NASA Institute for Advanced Concepts

9th Annual & Final Report | 2006 2007

Performance Period July 12, 2006 - August 31, 2007

NIAC

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NIAC
NASA Institute for Advanced Concepts

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◆ ACKNOWLEDGEMENTS ◆

The Universities Space Research Association wishes to acknowledge the dedication of the following people to NIAC's creative enterprise over the last nine years:

Dr. Robert A. Cassanova, Director

Dr. Diana Jennings, Associate Director

Dr. Ronald Turner, Senior Science Advisor

Ms. Sharon M. Garrison, NASA Coordinator for NIAC

Mr. Dale K. Little, Operations Manager

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Dr. Murray Hirschbein, NASA HQ Representative

Dr. Christopher Moore, NASA HQ Representative

Mr. Douglas A. Craig, NASA HQ Representative

Dr. John Cole, NASA MSFC Representative

Dr. Stanley Fishkind, NASA HQ Representative

All of the NIAC Fellows

All Members of the NIAC Science Council

The many NASA representatives for NIAC at NASA HQ & the NASA Centers

Numerous members of the popular and science news media, but especially Leonard David and Paul Gilster

Steve Heard, The Futures Channel

"Don't let your preoccupation with reality stifle your imagination."

Robert Cassanova & Sharon Garrison

MESSAGE FROM THE DIRECTOR

NIAC- A LEGACY OF REVOLUTIONARY CREATIVITY

Since its beginning in February 1998, NIAC has encouraged an atmosphere of creative examination of seemingly impossible aerospace missions and of audacious, but credible, visions to extend the limits of technical achievement. Visionary thinking is an essential ingredient for maintaining global leadership in the sciences, technology innovation and expansion of knowledge. NIAC has sought creative researchers who have the ability to transcend current perceptions of scientific knowledge and, with imagination and vision, to leap beyond incremental development towards the possibilities of dramatic breakthroughs in performance of aerospace systems.

By setting visionary standards for selection, NIAC has inspired the technical community to reach beyond current programs, reexamine scientific principles and visualize aerospace architectures and systems for which enabling technologies may not be available. The concepts selected by NIAC for further development have been examined by their peers based on criteria for technical credibility and revolutionary potential. Further examination of the selected advanced concepts is facilitated by NIAC to encourage feedback from a broad spectrum of the technical community and to expand the possibilities for further development by government, industry and private investors. As a result of NIAC's very active and inclusive process of nurturing advanced concepts, several of the advanced concept programs in government agencies and private industry have leveraged NIAC's investment and have provided additional funding for further development or noted the concepts in their long range plans. NIAC's visionary advanced concepts continue to inspire present and future generations of space scientists, engineers, and enthusiasts. In a modern setting where the presence of humans in space is now routine, the fact that NIAC captures the imagination of the general public and technical community represents a priceless contribution to our national space effort.

The staff of NIAC is honored to have had this opportunity to lead this unique institute and to have worked with the exceptionally creative NIAC Fellows and the many accomplished scientists and engineers who contributed to the peer review process, participated in oversight of NIAC's activities and provided continuing encouragement. We are also deeply indebted to the technical and public press as they have embraced NIAC's advanced concepts.

We are especially grateful for the funding provided by NASA over the last nine years and for the unwavering support of many exceptional scientists and engineers at NASA Headquarters and the NASA Centers. NIAC's legacy of revolutionary concepts and an atmosphere of scientific creativity will endure.

Robert A. Cassanova, Ph.D.
Director, NIAC

The NIAC Staff

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Diana Jennings, Ph.D.
Associate Director

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NASA Institute for Advanced Concepts

Executive Summary

Excellence is the result of caring more than others think is wise, risking more than others think is safe, dreaming more than others think is practical, and expecting more than others think is possible. (Mac Anderson)

Since 1998, the NASA Institute for Advanced Concepts (NIAC) has provided a process and a pathway for innovators with the ability for non-linear creativity to: (1) define grand visions for a future world of aeronautics and space, (2) explore the possibility of redefining realities of the future and (3) offer revolutionary solutions to the grand challenges of future aerospace endeavors.

By operating as a virtual institute with succinct proposal requirements and efficient peer review, NIAC's mode of operation emphasizes a flexible and open development of creative concepts with a minimum of technical direction. However, appropriate oversight and nurturing is provided by NIAC's contractual management and technical leadership plus timely collaboration with NASA's technical staff.

NIAC is an institute of the Universities Space Research Association created through contract with NASA in February 1998. Since then NIAC has received a total of 1,309 proposals and has awarded 126 Phase I grants and 42 Phase II contracts for a total value of $27.3 million. The awards spanned all categories of businesses with 45% to universities, 40% to small businesses, 7% to small and disadvantaged business, 2% to historically black colleges and universities and minority institutions, and 7% to large businesses.

NIAC's method of open review of its advanced concepts continued this year with a combination of open access to reports and briefings on the NIAC website, the NIAC Annual Meeting and the NIAC Phase I Fellows Meeting. Recipients of NIAC awards are designated as "NIAC Fellows". NIAC hosted the 8th NIAC Annual Meeting on October 17th and 18th in Tucson, AZ. The purpose of the meeting was to offer an opportunity for the currently funded Phase II Fellows and NIAC Student Fellows to present the results of their concept development efforts and to encourage the dialogue between all attendees. Invited keynote speakers, including Dr. Tony Tether of DARPA, gave thought-provoking presentations on space policy, cosmology, and advanced concepts in aeronautics and alternative-technology transportation. NIAC hosted its annual March Phase I Fellows meeting in Atlanta, GA. Also in this contract year NIAC visited many of NASA's Mission Directorates to continue its ongoing Grand Visions conversations with Associate Administrators or their designees. These conversations and documents augmented the NIAC's constantly evolving Grand Visions and informed the Call for Proposals released in November 2006. NIAC's technical leadership continued its vigorous activities for education, outreach and inspiration with presentations at universities, private industry and technical society meetings. NIAC and NIAC-sponsored advanced concepts received widespread recognition in the popular and technical press. NIAC Fellows were highly visible in technical society meetings with numerous presentations and publication of technical papers. In addition to inspiring proposals from the established technical community, NIAC continued a special program to encourage undergraduate students who have the potential for extraordinary creativity and the ability to stretch well beyond typical undergraduate course work. The NIAC Student Fellows Prize (NSFP), sponsored by Universities Space Research Association and managed by NIAC, was initiated in 2005 to attract these students and facilitate the development of their advanced aerospace concepts. Five students selected in May 2006 received a $9,000 one year grant and carried out their efforts during the 2006-2007 academic year.

In this, the ninth and final contract year, NIAC was asked to cease its concept solicitation activities in anticipation that the contract vehicle would be descoped and the contract ceiling reduced. The proposals received in response to CP 07-01 received their first round of reviews and feedback was provided to requestors. Phase I, Phase II and Student Prize calls were canceled. On August 31, 2007, NIAC ceased operations.

NIAC has inspired a legacy of revolutionary concepts that have been noted by the science oriented general public, the technical news media, private industry and government agencies. It is especially noteworthy that a number of the NIAC initiated concepts are now being substantially funded by government agencies and private industry or have been intellectually accepted in the long range plans of funding organizations. The NIAC philosophy and process has also inspired government and industry funding sources to reexamine their visions of future technical directions.

NIAC IMPACT

As the NIAC contract draws to a close, the NIAC staff has analyzed the Institute's output to assess impact. Because it is a primary deliverable, we have examined in particular Infusion of concepts into NASA and other agencies. Additionally, important value-added benefit has been contributed through training of students, communication with the public and education sectors, and more. This section describes these areas of contribution.

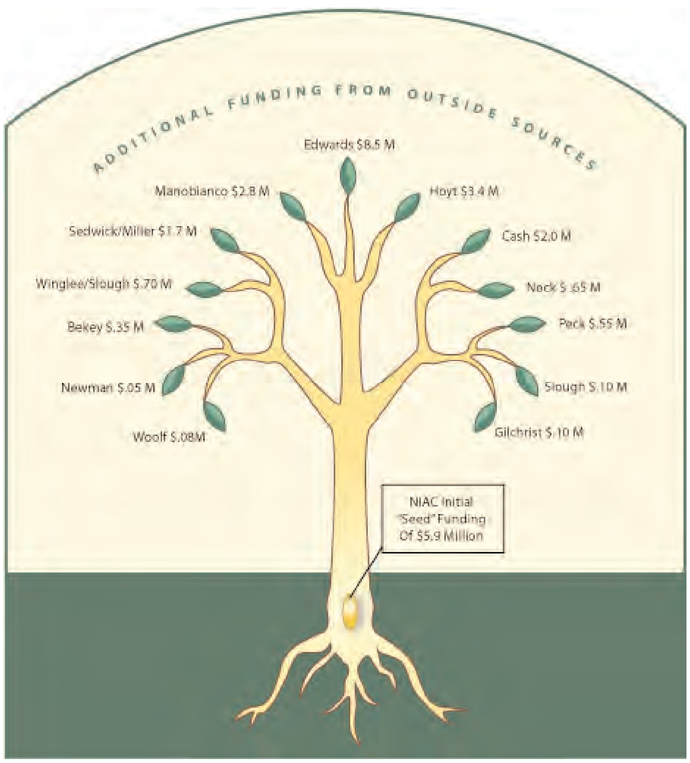


Figure 1. Outside support provided (in millions of dollars) beyond the NIAC investment. This graphic reflects thirteen NIAC concepts having an initial NIAC investment of $5.9 million dollars.

Leveraging of NIAC Support

Continuing support of advanced concepts development from other sectors is a form of return on investment (ROI) for NIAC. ROI is difficult to analyze for NIAC because the institute has only been in existence for 9 years, but focuses its activities on projects which will mature in ten to forty years. It is certain that the data we have so far represent only a portion of the economic assets that will be devoted to the realization of the most promising concepts. That said, to date numerous NIAC projects have become incorporated into the agency's plans; some have received follow-on funding from the agency; some have received additional funding from other agencies or the private sector.

Recently, we asked NIAC Fellows to provide us information about additional funding they may have received to continue NIAC-sponsored work. This summary describes a dozen efforts that have gone on to garner funding support from NASA or other sources. Initially funded by NIAC at the level of 5.9 million dollars, these efforts brought in at least $21.2 million dollars additional support from NASA, other agencies, and through the private sector. This estimate is a conservative one as some NIAC projects have trickle effects throughout the space sector, some produce spin-offs that are difficult to track but which also create ROI, and also because some projects become classified and data are no longer broadly available. It should be noted that ten of the projects were funded through Phase II. This means that to date, nearly 25% of Phase IIs have received further validation by additional funding. This is a significant measure of the excellent credibility of NIAC's results. The distribution of follow-on funding is summarized in Figure 1.

Because of the sheer diversity in NIAC projects, a case-by-case description follows:

The Space Elevator (Bradley Edwards, PI)
This effort sparked the creation of numerous businesses and attracted funding with a particular emphasis on the development of carbon nanotube materials. Space Elevator has been the focus of numerous prize competitions, including NASA's Centennial Challenges program. Additional support: at least $8.5 million. Future impact: billions if not trillions of dollars in launch savings relative to current methods. As one NIAC Fellow explained: "The Space Elevator would change everything."

Moon and Mars Orbiting Spinning Tether Transport (MMOSTT) (Robert Hoyt, PI)
Momentum exchange electrodynamic reboost (MXER) tethers represent magnitudes of reduction in cost for earth-to-orbit and in-space propulsion. Like the space elevator, tethers too have stimulated the development of new business so the data we have for additional funding is an underestimate. Additional funding has arisen from NASA, DARPA, and other sectors. Additional support: at least $3.4 million. Future impact: millions if not billions of dollars in launch and propulsion savings.

Global Environmental Micro Sensors (John Manobianco, PI)
This innovative atmospheric sensing system of in situ airborne probes garnered support from the Air Force and from NASA, as well as investment from ENSCO company funds. Protoyping will be carried out in concert with Kennedy Space Center this spring. Additional support: approximately $2.8 million. Potential impact: billions of savings as a consequence of enhanced forecast accuracy for weather-sensitive space launch and aviation industries, and mitigation of loss-of-life associated with violent storm trajectories.

The New Worlds Observer (Web Cash, PI)
This concept for planet finding was only months into its Phase II funding when it burst onto the global scene by gracing the cover of Nature. This concept has benefited from continuing support from NASA and more notably, at least $2 million in support for additional development from Northrup Grumman and its partners. Cash, the PI, says this concept would never have seen the light of day without NIAC backing. Additional support: at least $2 million. NASA GSFC has also contributed substantial in-kind support but we do not have numerical data. Potential impact: the same, or better, science return than the Terrestrial Planet Finder, at a savings of $5 billion.

Electromagnetic Formation Flying (Ray Sedwick and Dave Miller, PIs)
This system represents an important enabling technology for space missions, especially space telescopes or in deploying large structures. NIAC has funded a few formation flying concepts with this being most successful to date. Development of the EMFF continues with support from DARPA and STTR. Additional support totals $1.7 million. The potential impact will be the enabling of a whole new class of space telescopes and structures.

Global Constellation of Stratospheric Scientific Platforms (Kerry Nock, PI)
Constellations of stratospheric balloons could result in superior monitoring of environmental conditions. This project has seen further investment of $650,000 from NASA Centers and SBIR.

Mini-magnetospheric Plasma Propulsion (M2P2), (Robert Winglee and John Slough, PIs)
The M2P2 was included in the NASA Decadal Plan and funded by MSFC to continue experiments confirming computer models. A plasma sail review panel identified a number of technical issues needing further research before feasibility could be assessed. Subsequent research results have addressed most of these issues. Additional support: $700,000 to continue development of Helicon component.

Lorentz-Actuated Orbits: Electrodynamic Propulsion without a Tether (Mason Peck, PI)
This revolutionary concept relies on one of the last areas of classical physics that could be applied to propellantless propulsion. Additional funding: $550,000 from DARPA and NRO. Potential impact: significant cost-savings in propulsion.

Swarm Array Space Telescope (Ivan Bekey, PI)
This project received Phase I funding only. The use of this revolutionary telescope, employing a large membranous reflector element and a holographic crystal second stage, could represent significant upload mass savings over present next generation space telescope designs. Additional funding: $345,000 from NRO. Potential impact: not assessed.

Propagating Magnetic Wave Plasma Accelerator (John Slough, PI)
This project, funded only at the level of Phase I support, now enjoys annual support of $100,000 from the United States Air Force.

The Biosuit (Dava Newman, PI)
The Biosuit concept uses mechanical counter-pressure created by spray-on materials to provide a spacesuit that assists and protects astronauts at work on partial gravity surfaces. Additional follow-on funding from NIAC and NASA Headquarters has been directed towards this project. It is likely that other NASA center resources have been deployed. Additional funding: at least $50,000 from NASA with matching funds from NIAC and partial funding believed to be in place from at least one center. Potential impact: enhanced safety for astronaut EVA activities. Additionally, assistive technologies planned for the suit are now being prototyped for locomotion support for individuals suffering from gait disturbances following stroke.

Scalable Flat-Panel Nano-particle MEMS/NEMS Propulsion, (Brian Gilchrist, PI)
Currently in its first year of Phase II funding, this work utilizing a dramatically different form of charged-particle propulsion has already attracted additional funding from within the University of Michigan. Additional support: $100,000. Potential impacts on propulsion expected, and new studies will examine medical applications as well.

Very Large Optics for the Study of Extrasolar Terrestrial Planets (Nick Woolf, PI)
This concept is directly associated with the "Life Finder" that is specifically mentioned in the NASA Science long range plan. Additional funding was received from the National Reconnaissance Office for continued development of light-weight optical components. Additional support: $75,000.

Value-added

The final reports of NIAC Fellows, housed on the NIAC web site at www.niac.usra.edu, are the primary deliverable promised by USRA's contract with NASA. The work captured in these reports, and also published in technical reports, constitute the major intellectual output of NIAC. There is considerable value-added from these as well, particularly in the following areas:

Intellectual contributions or acceptance that have resulted in an agency putting resources into its own studies of a concept. For example, prompted by the success of a Phase I or Phase II concept, an agency convenes panels to study the work, includes it in a decadal plan, or otherwise funds R&D studies of its own. We indicated above work that elicited this response from NASA, e.g. the M2P2 study by Winglee and Slough. Another example is the Tailored Force Fields study by Narayanan Komerath. This not-yet-complete study has attracted interest from NASA Langley Research Center. Yet another example is the X-Ray Interferometry concept articulated by Webster Cash. Dubbed MAXIM, Micro Arcsecond X-ray Imaging Mission, this concept appeared in the National Academy Decadal Review of Astronomy released in 2000.

Unexpected spin-off technologies. For example, some NIAC studies have resulted in new medical technologies; the Biosuit is mentioned in this context. Another example is the work of Steve Dubowsky on hopping microbots; the materials used for the hopping apparatus are being developed for use in surgical procedures relying on real-time use of MRI instruments for positioning.

The training of technical PhD and Master's level students. Most NIAC-funded studies based in Universities utilize student research assistants, and while not yet compiled, we are aware of many PhD and Master's level projects conducted with NIAC support.

The production of new jobs. Some of our small business NIAC Fellows indicated that new jobs have been produced as a consequence of NIAC funding. In some cases new business divisions have been launched (Manobianco) or entire new businesses spawned (Space Elevator: e.g Black Line Ascension, Liftport).

Finally, an ongoing result of the NIAC investment has been, and will continue to be, inspiring both present and future generations of space scientists, engineers, and enthusiasts. In addition to the numerous publicity, inspiration and outreach activities of the past nine years, NIAC can point to two activities which will have long-lasting impacts on the public. The relationship between USRA-NIAC and The Futures Channel has resulted in the development of curriculum tools of particular use for middle- and high-school audiences. These will be relevant for up to twenty years because the concepts explored in the Futures Channel products have development timeframes of at least that long. The exhibits planned at the Chicago Museum of Science and Industry, utilizing NIAC concepts, are anticipated to be on view for decades as well. In a modern setting where the presence of humans in space is now routine, the fact that NIAC captures the public and technical imagination represents a priceless contribution to our national space effort.

Summary

NIAC continued in the ninth contract year to inspire, solicit, review, select, fund, nurture, and infuse revolutionary advanced concepts into NASA. The heart of the NIAC process is its two Calls for Proposals and the subsequent awards. The performance periods for all completed and currently planned awards are summarized in Table 1. The following sections describe the Calls that were awarded or initiated during the past year. Because the NIAC contract was descoped before the Phase I process for CP 07-01 was complete, there is no entry for this Call.

TABLE 1. Phase I and II Award Performance Periods

	2002	2003	2004	2005	2006	2007
	Jan-Dec	Jan-Dec	Jan-Dec	Jan-Dec	Jan-Dec	Jan-Dec
CP 01-01 Phase II Contracts	0101		Completed			
CP 01-02 Phase I Grants	0102	Completed				
CP 02-01 Phase II Contracts		0201				
CP 02-02 Phase I Grants		0202	Completed			
CP 03-01 Phase II Contracts			0301			
CP 04-01 Phase I Grants			0401	Completed		
CP 05-01 Phase I Grants				0501	Completed	
CP 05-02 Phase II Contracts				0502		
CP 06-01 Phase I Grants					0601	
CP 06-02 Phase II Contracts					0602	
CP 07-01 Phase I Grants						0701
CP 07-02 Phase II Contracts						0702

First USRA Contract Ends February 11

NIAC Funding Ends August 31

Completed Award Performance

No Awards Issued

Call for Proposals CP 05-02 (Phase II)

Phase II CP 05-02 was released on November 10, 2004 with a proposal due date of May 2, 2005. On this date, 15 proposals were received. Abstracts of concepts selected for an award are available in Appendix B and the NIAC website (htttp://www.niac.usra.edu). Phase II contracts began on September 1, 2005 (see Table 2).

Principal Investigator & Organization	CP 05-02 Concept Proposal Title
WENDY BOSS North Carolina State University	Redesigning Living Organisms for Mars
WEBSTER CASH University of Colorado, Boulder	New Worlds Imager
STEVEN DUBOWSKY Massachusetts Institute of Technology	Microbots for Large-Scale Planetary Surface and Subsurface Exploration
ELIZABETH McCORMACK Bryn Mawr College	Investigation of the Feasibility of Laser Trapped Mirrors
SIMON WORDEN Steward Observatory, University of Arizona	A Deep Field Infrared Observatory near the Lunar Pole

TABLE 2. CP 05-02 Phase II Award Winners

Call for Proposals CP 06-01 (Phase I)

Phase I CP 06-01 was released on November 30, 2005 with a proposal due date of February 13, 2006. On this date, 166 proposals were received. The applicable statistics pertaining to type of submitting organization and award recipients are summarized in Table 3. Abstracts of concepts selected for an award are available in Appendix C and on the NIAC website (htttp://www.niac.usra.edu). Table 4 lists CP 06-01 Phase I awards. Grants began on September 1, 2006.

Business Category	Proposals Received	Awarded
Universities	45	4
Small Disadvantaged Businesses	15	1
Small Businesses	97	6
Historically Black Colleges & Universities	2	0
Large Businesses	7	0
Total Proposals Received for CP 06-01	**166**	**11**

TABLE 3. Summary of CP 06-01 Responding Organizations

Principal Investigator & Organization	CP 06-01 Concept Proposal Title
DAVID AKIN University of Maryland Space Systems Laboratory	Development of a Single-Fluid Consumable Infrastructure for Life Support, Power, Propulsion, and Thermal Control
ROGER ANGEL University of Arizona Steward Observatory	Practicality of a Solar Shield in Space to Counter Global Warming
DEVON CROWE Physical Sciences, Inc.	Self-Deployed Space or Planetary Habitats and Extremely Large Structures
TOM DITTO DeWitt Brothers Tool Company	Primary Objective Grating Astronomical Telescope
ROBERT HOYT Tethers Unlimited, Inc.	Reduction of Trapped Energetic Particle Fluxes in Earth and Jovian Radiation Belts
MASON PECK Cornell University College of Engineering	In-Orbit Assembly of Modular Space Systems with Non-Contacting, Flux-Pinned Interfaces
JOE RITTER University of Hawaii Institute for Astronomy	Large Ultra-Lightweight Photonic Muscle Telescope
MATTHEW SILVER IntAct Labs, LLC	Bio-Electric Space Exploration
JOHN SLOUGH University of Washington	Plasma Magnetic Shield for Crew Protection
GUILLERMO TROTTI Trotti & Associates, Inc.	Extreme eXPeditionary Architecture (EXP-Arch): Mobile, Adaptable Systems for Space and Earth Exploration
GEORGE WILLIAMS Ohio Aerospace Institute	Spacecraft Propulsion Utilizing Ponderomotive Forces

TABLE 4. CP 06-01 Phase I Award Winners

Call for Proposals CP 06-02 (Phase II)

Phase II CP 06-02 was released on December 1, 2005 with a proposal due date of May 3, 2006. On this date, 14 proposals were received. The applicable statistics pertaining to type of submitting organization and award recipients are summarized in Table 5. Abstracts of the selected concepts (Table 6) are available in Appendix D and on the NIAC website (htttp://www.niac.usra.edu). Phase II contracts began September 1, 2006. Normally up to two years in duration, because of the NIAC contract termination these awards ended on August 31, 2007.

Business Category	Proposals Received	Awarded
Universities	4	2
Small Disadvantaged Businesses	1	1
Small Businesses	8	1
Historically Black Colleges & Universities	0	0
Large Businesses	1	1
Total Proposals Received for CP 06-02	**14**	**5**

TABLE 5. Summary of CP 06-02 Responding Organizations

Principal Investigator & Organization	CP 06-02 Concept Proposal Title
YOUNG K. BAE Bae Institute	A Contamination-Free Ultrahigh Precision Formation Flight Method Based on Intracavity Photon Thrusters and Tethers: Photon Tether Formation Flight
JIM BICKFORD Draper Laboratory, Inc.	Extraction of Antiparticles Concentrated in Planetary Magnetic Fields
BRIAN GILCHRIST University of Michigan	Scalable Flat-Panel Nanoparticle MEMS/NEMS Propulsion Technology for Space Exploration in the 21st Century
MASON PECK Cornell University	Lorentz-Actuated Orbits: Electrodynamic Propulsion Without a Tether
NESTOR VORONKA Tethers Unlimited, Inc.	An Architecture of Modular Spacecraft with Integrated Structural Electrodynamic Propulsion (ISEP)

TABLE 6. CP 06-02 Phase II Award Winners

Call for Proposals CP 07-01 (Phase I)

Phase I CP 07-01 was released on December 4, 2006 with a proposal due date of February 12, 2007. On this date, 113 proposals were received. The applicable statistics pertaining to type of submitting organization and award recipients are summarized in Table 7. The peer review process was launched but terminated early because of the pending NIAC contract termination. Feedback was provided upon request from proposers.

Business Category	Proposals Received
Universities	29
Small Disadvantaged Businesses	5
Small Businesses	77
National Laboratories	1
Large Businesses	1
Total Proposals Received for CP 07-01	**113**

TABLE 7. Summary of CP 07-01 Responding Organizations

Call for Proposals CP 07-02 (Phase II)

The Call for Proposals for CP 07-02 was prepared, but was not released due to pending contract termination.

Financial Performance

The NIAC measures its financial performance by how well it minimizes its operational expenses in order to devote maximum funds to viable advanced concepts. For this reporting period, 71% of the NIAC's total budget was devoted to advanced concept research and development. We take great pride in this achievement.

NIAC Student Fellows Prize Call For Proposals 2006-2007

The NIAC Student Fellows Prize (NSFP), sponsored by Universities Space Research Association and managed by NIAC, was initiated in 2005 to attract these students and facilitate their studies. The Prize, in the amount of $9,000 dollars, is intended to foster mentoring, networking, and creativity, and is a student's first opportunity to exercise responsibility in project management.

The call for proposals for the Prize for academic year 2006-2007 was released in January 2006 with a due date of April 17, 2006. Fourteen proposals were received and on May 5, 2006 five students were selected (Table 8). Students began work on September 1, 2006. Each of the winners was responsible for three progress reports as well as two presentations: the first, a poster presentation at NIAC's Annual meeting and the second, a briefing delivered at NIAC's Fellows meeting.

The Winners of the NIAC Student Fellows Prize for Academic Year 2006-2007 are:

Student & Affiliation	Concept Proposal Title
J. MICHAEL BURGESS University of Alabama, Huntsville	Advanced Grazing Incidence Neutron Imaging System
DANIELLA DELLA-GUISTINA University of Arizona	The Martian Bus Schedule: An Innovative Technique for Protecting Humans on a Journey to Mars
JONATHAN SHARMA Georgia Institute of Technology	START: Utilizing Near-Earth Asteroids with Tether Technologies
FLORIS VAN BREUGEL Cornell University	Evolution of a Scalable, Hovering Flapping Robot
RIGEL WOIDA University of Arizona	The Road to Mars

TABLE 8. 2006-2007 NIAC Student Fellows Prize Winners

NIAC Student Fellows Prize Call for Proposals 2007-2008

The call for proposals for the Prize for academic year 2007-2008 was released in January 2007 with a due date of April 17, 2007. Because of the termination of the NIAC contract, the Student Fellows Prize Call was cancelled in March 2007.

Release and Publicity of Calls for Proposals

There were various methods used to release and publicize the NIAC Phase I and Student Fellows Prize Calls for Proposals. Some of the ways that NIAC solicited Calls to the Community follow.

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 (American Institute for Aeronautics and Astronautics, American Astronautical Society, the American Astronomical Society and the American Society of Gravitational & Space Biology); Announcements on the USRA and NIAC web sites; Web links from NASA Mission Directorate's Web pages; Web link from the NASA Coordinator's Web page; Announcements to a distribution list for Historically Black Colleges & Universities (HBCU), minority institutions (MI) and small disadvantaged businesses (SDB) provided by NASA; Distribution of announcements to an Earth Sciences list provided by NASA GSFC; and Announcements distributed at technical society meetings. Distribution of the NIAC Student Fellows Prize (NSFP) Announcement also occurs through the Space Grant College Directors and the USRA Council of Institutions.

Peer Reviewer Recruitment

The NIAC leadership 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. NIAC continuously recruited experts across a broad cross-section of technical expertise and a total of 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 recruited 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.

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.

NIAC 8th Annual Meeting

The NIAC 8th Annual Meeting was held at the Marriott University Park Hotel in Tucson, Arizona on October 17-18, 2006. The agenda included keynote speakers on topics of special interest, status reports by one Phase III Fellow, and ten Phase II Fellows, posters by 11 Phase I Fellows and 5 Student Fellows, and a tour of the University of Arizona mirror lab. Approximately 110 people attended, including representatives of NASA and other agencies, business people, and members of the public. Presentations from the meeting are available on the NIAC website.

Left: Poster Sessions; Center: Dava Newman Interview; Right: Roger Angel Mirror Lab Tour

Left: CP 06-02 NIAC Fellows; Right: CP 06-01 NIAC Fellows

The following individuals presented keynote addresses:

Dr. Anthony Tether, Director of DARPA
William Pomerantz, Director of Space Projects, X PRIZE Foundation
Dr. Sean Carroll, California Institute of Technology

In addition, Paul Mexcur (NASA) gave an overview of NASA's SBIR/STTR program and Bob Scaringe (AVG Communications) discussed the process for marketing advanced concepts.

KEYNOTE SPEAKERS:

William J. Pomerantz

Director of Space Projects, X PRIZE Foundation

Mr. Pomerantz currently serves as the Director of Space Projects for the X PRIZE Foundation. He holds a BA in Earth and Planetary Sciences from Harvard University. He served as a Research Associate in the NASA Academy at Goddard Space Flight Center, NASA's premiere leadership training program. After graduating from the Academy, Mr. Pomerantz worked as a planetary geologist studying

Martian geology in the lab of James Head, III at Brown University for one year before leaving to earn his MS in Space Studies at the International Space University (ISU). After graduating from ISU, Mr. Pomerantz worked as an Analyst at the Futron Corporation, an aerospace consultancy based in Bethesda, Maryland. In July of 2005, Mr. Pomerantz took the position of Director of Space Projects at the X PRIZE Foundation, where he currently manages all of the Foundation's new prizes in the field of aerospace, totaling more than $2.5 million in total prize money. Mr. Pomerantz is also the co-founder and editor of SpaceAlumni.com, an online news and networking tool for young space professionals around the world. In 2006, Mr. Pomerantz was selected to serve on a National Research Council (NRC) Federal Advisory Committee producing a report on "Meeting the Workforce Needs for the National Vision for Space Exploration".

Dr. Anthony J. "Tony" Tether, Director,
Defense Advanced Research Projects Agency (DARPA)

Dr. Tether received his Bachelor's of Electrical Engineering from Rensselaer Polytechnic Institute in 1964, and his Master of Science (1965) and Ph.D. (1969) in Electrical Engineering from Stanford University. Dr. Anthony J. Tether was appointed as Director of the Defense Advanced Research Projects Agency (DARPA) on June 18, 2001. As Director, Dr. Tether is responsible for management of the Agency's projects for high-payoff, innovative research and development. Until his appointment as Director, DARPA, Dr. Tether held the position of Chief Executive Officer and President of The Sequoia Group, which he founded in 1996. The Sequoia Group provided program management and strategy development services to government and industry. From 1994 to 1996, Dr. Tether served as Chief Executive Officer for Dynamics Technology Inc. From 1992 to 1994, he was Vice President of Science Applications International Corporation's (SAIC) Advanced Technology Sector, and then Vice President and General Manager for Range Systems at SAIC. Prior to this, he spent six years as Vice President for Technology and Advanced Development at Ford Aerospace Corp. He has also held positions in the Department of Defense, serving as Director of DARPA's Strategic Technology Office in 1982 through 1986, and as Director of the National Intelligence Office in the Office of the Secretary of Defense from 1978 to 1982. Dr. Tether has served on Army and Defense Science Boards and on the Office of National Drug Control Policy Research and Development Committee.

Dr. Sean Carroll
California Institute of Technology, Department of Physics

Sean Carroll is a Senior Research Associate at the California Institute of Technology. He received his Ph.D. from Harvard University, and has served as a postdoctoral researcher at the Center for Theoretical Physics at MIT and the Institute for Theoretical Physics at the University of California, Santa Barbara, and on the faculty of the University of Chicago. His research ranges over a number of topics in theoretical physics, focusing on cosmology, field theory, particle physics, and gravitation. Issues addressed by this research include the nature of dark matter and dark energy, the connection of cosmology to quantum gravity and string theory, and whether the early universe underwent a period of inflationary expansion. Carroll has written a graduate textbook, "Spacetime and Geometry: An Introduction to General Relativity", published by Addison-Wesley. He has been awarded fellowships from the Sloan and Packard foundations, as well as the MIT Graduate Student Council Teaching Award.

Students were very active at the meeting. All five of the Prize winners discussed their posters with Science Council members and were also given written feedback.

Associate Director Diana Jennings (l) and Daniella Della-Guistina (r)

During the meeting, the John McLucas Astronaut Safety Research Prize was awarded to NIAC Student Fellow Daniella Della-Guistina of the University of Arizona for her project "The Martian Bus Schedule; An Innovative Technique for Protecting Humans on a Journey to Mars". She was awarded this prize by trustees of the Arthur C. Clarke Foundation.

NIAC Fellows Meeting

The NIAC Fellows Meeting was held on March 6-7, 2007 near the NIAC Headquarters in Atlanta. Speakers at the meeting included all of the currently funded CP 06-01 Phase I Fellows and Student Fellows for 2006-2007 all of whom gave short status reports about their advanced concepts. Moon expert Paul Spudis gave a keynote address as did NIAC Senior Scientist and Space weather expert Ron Turner. A panel led by Bob Scaringe of AVG communications featured panelists with specific expertise on "After NIAC" funding opportunities. Discussants on the topic of "Funding After NIAC" were Doug Comstock, NASA Innovative Partnerships Program, Paul Eremenko, Booz-Allan Hamilton, George Petracek, Altrium Communications, and Rahul Saxena, Seraph Group. The panel was chaired by Bob Scaringe, AVG Communications. Approximately 60 people attended, including a large number of NASA personnel. Presentations from the meeting are available on the NIAC website (www.niac.usra.edu).



NIAC Fellows Gui Trotti and Dava Newman (left); Science Council members James Sinnett and Donna Shirley (center); NIAC Fellow Joe Ritter (right)

"Funding After NIAC" panel discussion

KEYNOTE SPEAKERS:

DR. PAUL D. SPUDIS

Dr. Spudis is Principal Professional Staff at the Johns Hopkins University Applied Physics Laboratory. He received his education at Arizona State University (B.S., 1976; Ph. D., 1982) and at Brown University (Sc.M., 1977). His research focuses on the processes of impact and volcanism on the planets. He has served on numerous NASA committees and panels and on the Committee for Planetary and Lunar Exploration (COMPLEX), an advisory committee of the National Academy of Sciences. In 1990-1991, he was a member of the Synthesis Group, a White

House panel that analyzed a return to the Moon. He was Deputy Leader of the Science Team for the Department of Defense Clementine mission to the Moon in 1994 and is the Principal Investigator of an imaging radar experiment on the Indian Chandrayaan-1 mission, to be launched to the Moon in 2008. In 2004, he was a member of the President's Commission on the Implementation of U. S. Space Exploration Policy and was presented with the NASA Distinguished Public Service Medal for that work. He is the recipient of the 2006 Von Karman Lectureship in Astronautics, awarded by the American Institute for Aeronautics and Astronautics. He is the author or co-author of over 100 scientific papers and four books, including The Once and Future Moon, a book for the general public in the Smithsonian Library of the Solar System series, and (with Ben Bussey) The Clementine Atlas of the Moon, published in 2004 by Cambridge University Press.

DR. RONALD TURNER

Dr. Turner has more than 26 years of experience in space systems analysis. In addition to his role as Senior Science Advisor to the NASA Institute for Advanced Concepts (NIAC), Ron is an internationally recognized expert in radiation risk management for astronauts, particularly in response to solar storms. For the past eight years he served as Principal Investigator on NASA research grants investigating risk management strategies for solar particle events during human missions to the Moon or Mars. He is a Participating Scientist on the Mars Odyssey program, where he is working with radiation measurements from Odyssey instruments orbiting Mars. He is a member of the National Research Council (NRC) Committee on Solar and Space Physics and the NRC Committee for the Evaluation of Radiation Shielding for Space Exploration. He previously served on NRC Committees looking at space radiation hazards and the vision for space exploration (results published in October 2006) and precursor measurements necessary to support human operations on the surface of Mars (results published in May 2002). Dr. Turner's PhD, from the Ohio State University, is a multi-disciplinary degree covering Nuclear/ Particle/ Astrophysics. He received his Masters and Bachelor's degrees from the University of Florida. He is a member of the American Institute of Aeronautics and Astronautics, the American Geophysical Union, the International Academy of Astronautics, and the American Astronautical Society.

NIAC Science Council Meetings

The NIAC Science Council met with the NIAC leadership and USRA management immediately following the October 2006 Annual Meeting. The Council met again with the USRA President, the NIAC leadership and the NASA COTR following the March 2007 Fellows Meeting. The Council meetings began with an informal dinner after the adjournment of the NIAC meetings and continued on the next day. The NIAC technical leadership (Director, Associate Director and Senior Science Advisor) presented status reports of all NIAC activities since the last Council meeting and discussed the plans for the next 12 months. The meetings concluded with the Council giving a summary of their observations and recommendations. The membership of the Science Council in the final contract year is listed in Table 14.

Coordination with NASA

Since NIAC's inception, Sharon Garrison (right) has served as the NASA Coordinator for NIAC and as such was the primary point-of-contact between NIAC and NASA. For the bulk of this contact year, Ms. Garrison resided in the Advanced Concepts and Technology Office (ACTO) of the Flight Program and Projects Directorate at NASA's Goddard Space Flight Center (GSFC). Ms.

Garrison actively communicated throughout NASA to a review team comprised of representatives from the Mission Directorates and Centers. Table 9 is a listing of these representatives. Throughout the process of managing NIAC, these representatives were kept informed by Ms. Garrison of the status of the Institute and were appropriately involved in decisions and feedback. NIAC provided monthly contract status reports and an annual report to the NASA Coordinator who forwarded these reports to the support team and others within NASA.

NASA COTR	NASA Headquarters	NASA Mission Directorates	NASA Centers
Sharon Garrison	Chris Moore	***Aeronautics:*** Murray Hirschbein ***Exploration Systems:*** Jitendra Joshi Chris Moore **Program Analysis & Evaluation:** Jason Derleth ***Science:*** Gordon Johnston Mariann Albjerg ***Space Operations:*** Stanley Fishkind Bradley Carpenter	ARC: Larry Lasher DFRC: Greg Noffz GRC: Daniel Glover GSFC: Peter Hughes JPL: Neville Marzwell JSC: John Saiz KSC: Robert Youngquist LaRC: Dennis Bushnell MSFC: John Cole SSC: Bill St. Cyr

TABLE 9. The NASA-NIAC Support Team

Throughout the contract the NIAC leadership briefed Associate Administrators and other senior technical staff at NASA Headquarters as well as Directors of NASA Centers. The purpose of these briefings was to facilitate the eventual transition of NIAC advanced concepts into NASA long range plans, to inform them about the plans for NIAC, and to seek their active support and feedback. Yearly, NASA was requested to provide Grand Visions for use in future NIAC Calls for Proposals. This year the NIAC placed particular emphasis on this requirement with visits to all of the Mission Directorates as well as the Office of Strategic Communication and the office for Program Analysis and Evaluation. In addition, NASA technical staff presented overviews of related NASA advanced concept activities to the NIAC Director. NIAC also participated in student programs sponsored through the NASA Centers. Table 10 describes NIAC's coordination with NASA during this contract year.

NASA ACADEMY	Jul. 20, 2006	Diana Jennings gave an invited seminar to 20 students and 2 staff members at Goddard's NASA Academy. Sharon Garrison also attended. The seminar included a dinner with the students and informal discussions. USRA/NIAC brochures and NIAC pins were distributed.
NASA HQ, Program Analysis and Evaluation (PA&E)	Nov. 8, 2006	Bob Cassanova, Diana Jennings, Ron Turner and Sharon Garrison provided a status briefing to Scott Pace and Jason Derleth of PA&E. Grand visions were also discussed.
NASA HQ: Aeronautics Research Mission Directorate (ARMD)	Nov. 14, 2006	Bob Cassanova, Diana Jennings, and Ron Turner provided a status briefing to Jaiwon Shin and Murray Hirschbein of ARMD. Grand visions were also discussed.
NASA HQ: Innovative Partnerships Program (IPP)	Nov. 15, 2006	Bob Cassanova, Diana Jennings, Ron Turner and Sharon Garrison provided a status briefing to Doug Comstock, Diane Powell, Carl Ray, and John Yadvish of the IPP. The group also discussed the possibility of NIAC being placed in IPP.
NASA HQ: Science Mission Directorate (SMD)	Dec. 8, 2006	Diana Jennings, Ron Turner and Sharon Garrison provided a status briefing to George Komar and Gordon Johnston of SMD. Grand visions were also discussed.
NASA HQ: Office of Communications Planning (OCP)	Dec. 8, 2006	Diana Jennings, Ron Turner and Sharon Garrison provided a status briefing to Robert Hopkins and Kristin Erickson of OCP. Sharon Garrison shared a large number of significant items of publicity about NIAC-sponsored concepts.
NASA HQ: Space Operations Mission Directorate (SMD)	Mar. 9, 2007	Diana Jennings, Ron Turner and Sharon Garrison, met with representatives of the Space Operations Mission Directorate. SOMD AA Bill Gerstenmeier and Deputy AA Lynn Cline were present. Other participants included Bill Hawes, Jason Crusan, Tom Whitmeyere, Sam Scimemi, John Rush, and Brad Carpenter. A status briefing was given and grand visions discussed.

TABLE 10. Contacts with NASA

Publicity, Inspiration and Outreach

The NIAC has throughout its operation sought out innovators of all ages and backgrounds to participate in the process of expanding our future possibilities. NIAC interacts with technical communities, the educational community and the public at large. Appendix E provides a listing of the inspiration and outreach activities conducted during the ninth contract year of operation.

In the ninth contract year, the accomplishments of NIAC Fellows created a near-constant demand for information. Press releases, often orchestrated through talented NASA staff, captured the attention of press outlets around the world. A listing of publicity appearances is included in Appendix F. The NIAC staff was consistently available for public comment and as resources for a broad array of publications, podcasts, radio and television programming, acting too as a conduit for the media to directly interface with NIAC Fellows. During the ninth year of contract operation, the work of the NIAC was featured in numerous highly visible publications and programs, including Nova, features on the Discovery Channel, Wired, and The Christian Science Monitor. The World Wide Web also carried numerous stories for NIAC Fellows on popular sites such as Space.com and CNN.com. NIAC research and activities received additional exposure through blog discussions throughout the Internet.

Many National and International Publications Feature Articles about NIAC.

General and educational outreach was accomplished in many ways, such as through the NIAC website and distribution of NIAC brochures and lapel pins. In addition, NIAC Annual Meetings and Fellows Meetings were open to the general public and with no cost for admission or registration. Some NIAC Fellows actively engaged students in classwork aimed at the development of advanced concepts or participated in outreach activities within their home organizations. NIAC staff members frequently spoke at schools, museums, and to student groups. The work of NIAC Fellows was featured on the Futures Channel, a well-known developer of educational materials. Four videos are available at www.thefutureschannel.com.

The Chicago Museum of Science and Industry will use many NIAC Fellows' concepts in their Technology Gallery and also in a major exhibit, “Exploration Mars”. The latter exhibit is planned to begin in 2011 and will run from 20 - 50 years.

Historically, a constant flow of information has passed between the technical community and NIAC, especially through the web site and by presentations at technical meetings. NIAC actively pursued exposure with aerospace industry associations through presentations, often as an invited participant, to these organizations. The NIAC leadership and NIAC Fellows also presented invited seminars at universities, non-NASA research agencies and non-aerospace industries and associations. The NIAC annual meeting and the annual NIAC Phase I Fellows meeting provided opportunities for open analysis and advocacy of currently funded advanced concepts as well as an unbiased and open-minded examination of revolutionary concepts and enabling technologies.

The leadership of NIAC, including the Director, Associate Director and Senior Science Advisor, promoted revolutionary advanced concepts through participation, primarily by invitation, on steering and oversight committees organized by NASA and other civilian agencies, Department of Defense, National Academy of Sciences, and National Research Council committees. NIAC regularly interfaces with other U.S. research agencies to (1) stay informed about technology breakthroughs developed by these agencies; (2) encourage feedback to NIAC Fellows from a diverse constituency of research organizations; (3) explore the potential for supplemental funding for NIAC advanced concepts; and (4) establish links with the community of researchers funded by these agencies.

Survey of Technologies to Enable NIAC Concepts

Beginning with the fifth Annual Report that covered the contract performance period ending in July 2003, NIAC has surveyed the critical enabling technologies for the NIAC Phase II concepts. The purpose of this survey is to provide NASA with inputs to their investment strategy for advanced technologies that would enable further development of the NIAC concept and provide

	Table 11. CP 03-01 Critical Enabling Technologies
KOMERATH	Large-scale direct conversion of solar energy to tunable radio and microwave frequencies
	Robotic sintering of lunar regolith and NEO material
	Large tuned conversion devices based on "vacuum" tube technology, where the vacuum of space is used in lieu of a tube
	Direct Conversion of sunlight to microwave and/or laser power
	Power beaming with high efficiency at the sender and the receiver
MAVROIDIS	Biology-inspired-nano-robotics
	Network based space sensing for planetary environments
	Radiation responsive molecular assembly
	Bio-nano-components such as actuators, joints, sensors etc.
	Distributive intelligence, programming and control
	Signaling and information flow
	Simulation of dynamics of bio-nano-structures
PANKINE	Advanced balloon envelope materials
	Lightweight balloon guidance and autonomous navigation
	Reliable and robust entry descent and inflation (EDI) systems
	Advanced power generation and energy storage
	Compact science sensors and lightweight dropsondes
SLOUGH	Advanced power processing unit
	Solar wind detection system
	Advanced guidance systems
TODD	Pioneer organisms
	Laboratory ecopoiesis test bed
	Efficient and safe miniaturized simulated planetary environments
	Access to extraterrestrial venues
	Novel laboratory information networks
	Microbial health assessment

additional justification for general categories of advanced technologies that may enable a broad range of future missions.

	Table 12. CP 05-02 Critical Enabling Technologies
ANGEL	Cryogenic liquid of very low vapor pressure able to accept and hold a mirror-like evaporated surface
	Friction-free superconducting bearing and drive system
	Mechanical and control elements with a 50 year lifetime
	Dust resistant and durable robotics for construction and excavation
	Lunar infrastructure support
	Site-test lunar precursor lander
BOSS	Plants that can withstand the environments that will be sustained in extraterrestrial greenhouses
	Earth-based robotic lunar/Martian test-chambers that accurately simulate the environmental conditions on extraterrestrial sites such as the moon and Mars
	Access to extraterrestrial greenhouses
	Biosensors to monitor the greenhouse conditions and plants redesigned to survive under extreme conditions
CASH	Easily relocatable spacecraft
	Advanced station-keeping
	Large shaped deployables
	Low scatter surfaces and edges
	Advanced precision formation flying
	Low noise interferometers
	Large deployable telescopes
DUBOWSKY	Micro fuel cells (mm scale)
	Low weight high capacity hydrogen and oxygen storage element
	High performance very light weight actuators, micro-sensors for planetary exploration, and advanced guidance systems
	Sensors that are very small, low power and robust
	Algorithms for group behaviors for teams of planetary robotics systems
	New non-line of sight communication technology
McCORMACK	Nanotechnology suitable to producing the ~ 1018 particles required for an orbiting laser trapped mirror
	Extremely stable, long-lived, high-power lasers suitable for continuous use on orbit for periods of 3 to 5 years
	Improved sunshield technology
	Technology for neutralizing accumulated charge on the delicate grid of particles comprising the trapped mirror surface
	Advanced orbital energy management, communication, station-keeping and other infrastructure to enable a range of innovative orbit options

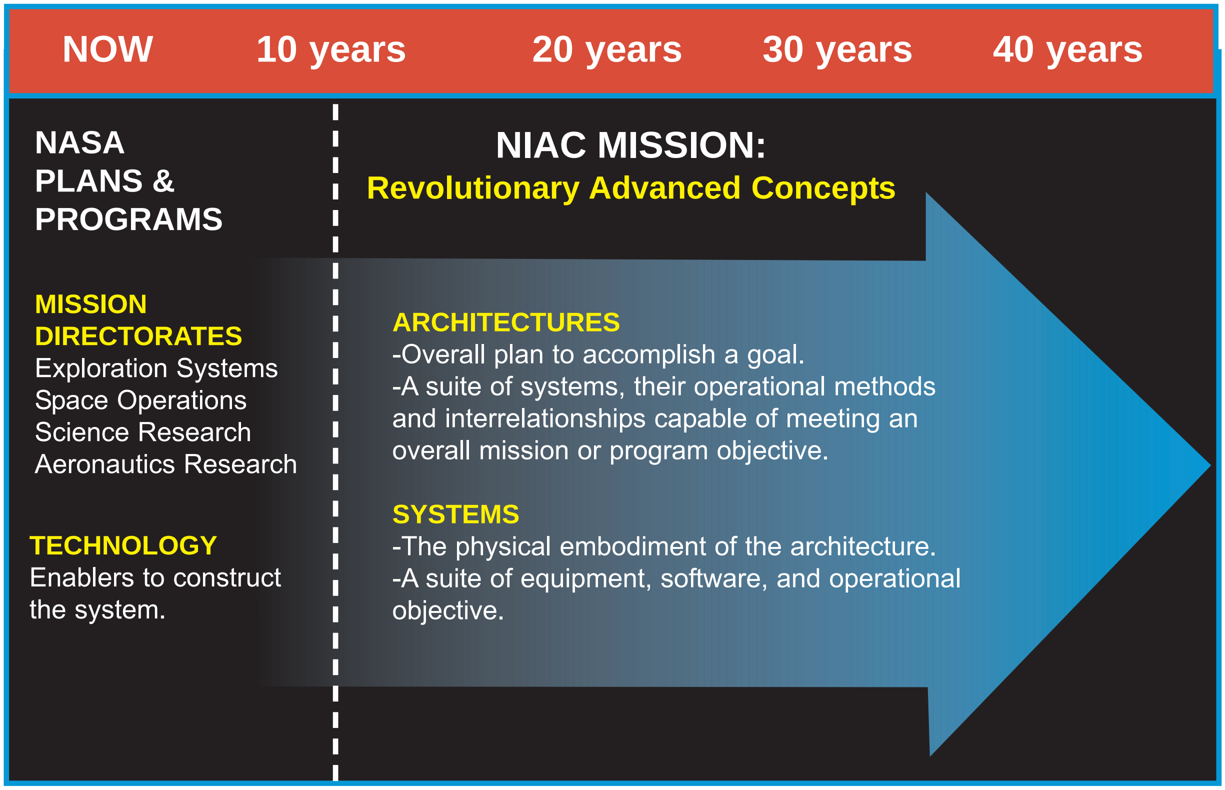
Three sets of Phase II contracts were actively funded during this contract year. Five CP 03-01 advanced concepts were near the end of their second year (performance period from October 2004 through September 2006). Five CP 05-02 advanced concepts were in their second year (performance period from September 2005 through August 2007). Five CP 06-02 advanced concepts were in their first year (performance period from September 2006 through August 2007)

Each of these Phase II Fellows was asked to respond to the following questions related to critical technologies to enable their concept: (1) What are the three most critical technologies to enable the further development of your NIAC concept? Please give a brief explanation, two or three sentences, describing the critical relationship of each technology to your concept. (2) What are the other technologies that are important for the further development of your concept? Please briefly describe their relationship to your concept. The fourteen responses are completely reported in Appendix A along with short explanations of the relationship of each technology to the advanced system or architecture (Tables 11, 12 and 13).

	Table 13. CP 06-02 Critical Enabling Technologies
BAE	Engineering space flight-ready photon thrusters
	Integration of photon thrusters with precision interferometric ranging systems
	Integration of tether systems with optical systems
	Overall dynamics control system
	Target alignment, scanning and retargeting technologies
	Launch and deployment technologies
BICKFORD	Low mass, high strength, long strand, ultra-high current loops
	Radiation tolerant in-orbit power source
	Compact mass spectrometer placed in highly eccentric orbit
	Antiproton catalyzed fission/fusion engine
	Passive cooling systems
	Affordable lift
PECK	Lightweight self-capacitive materials and structures
	Compact self-capacitive materials and structures
	High-voltage power systems to maintain high spacecraft charge
	Materials compatible with high-potential environments
	Materials with high photoelectric currents
VORONKA	Plasma contactor that enables efficient collection and transmission current between the ISEP system and the ambient space plasma
	Highly efficient energy collection, processing and storage modules
	High current density, high temperature superconducting wire
	Controls laws for low-thrust propulsion systems

DESCRIPTION OF THE NIAC

The NIAC MISSION



This section provides a description of the organization, function, and process of the NASA Institute with particular reference to the ninth contract year of operation. The NASA Institute for Advanced Concepts (NIAC) was formed to provide an independent source of revolutionary aeronautical and space concepts that could dramatically impact how NASA develops and conducts its missions. The Institute provided a highly visible, recognized and agency-level entry point for outside thinkers and researchers. The ultimate goal of NIAC was to infuse the most promising NIAC-funded advanced concepts into NASA plans and programs. Throughout its operation, the Institute functioned virtually, utilizing the Internet whenever productive and efficient for communication with grant and subcontract recipients, NASA, and the science and engineering communities.

NIAC FOCUS

Revolutionary concepts for systems and architectures that can have a major impact on future missions of the NASA Enterprises, inspire the general public, and excite the nation's youth.

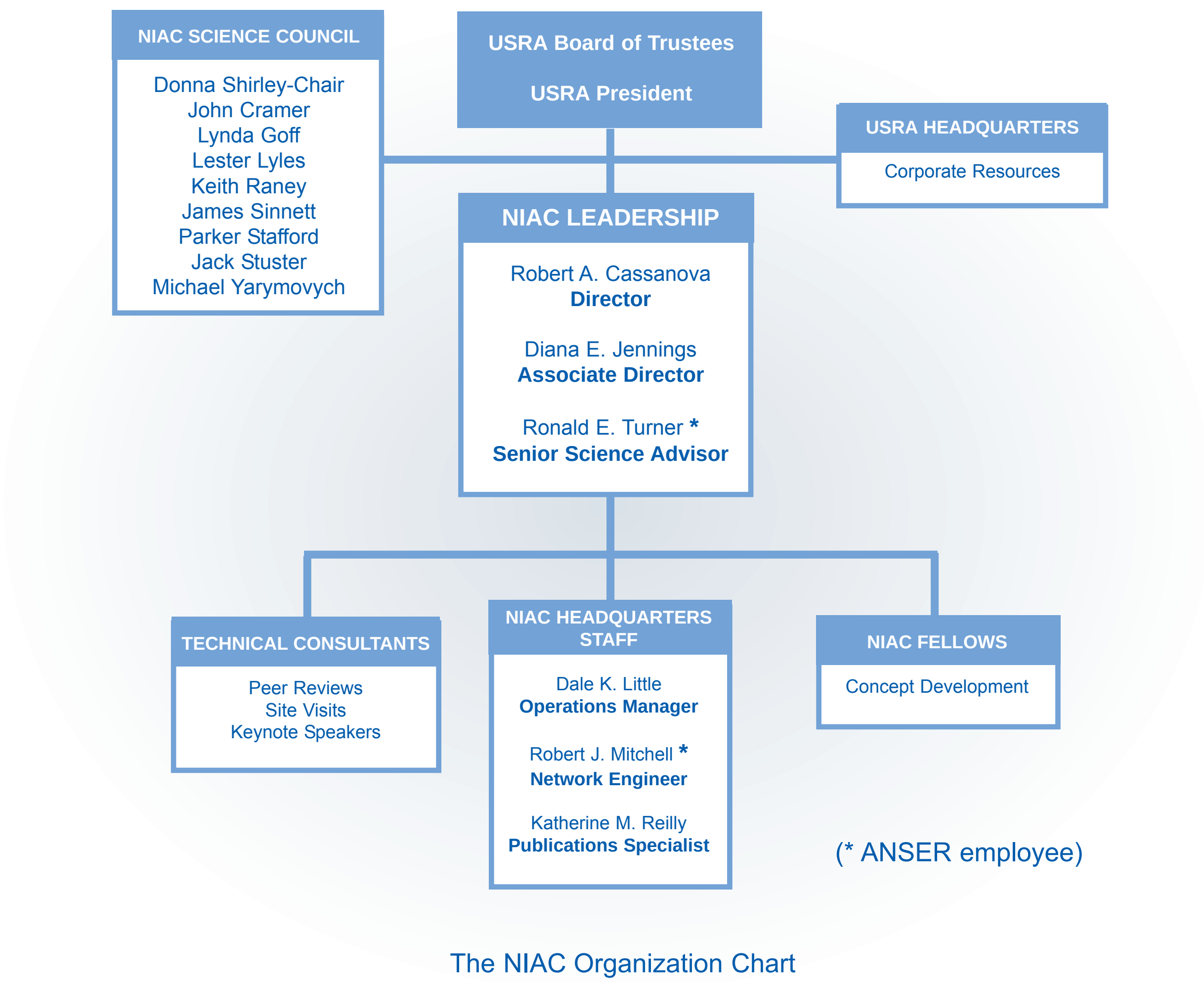
NIAC METHOD

Provide a pathway for innovators with the ability for non-linear creativity to explore revolutionary responses to the grand visions of future aerospace endeavors.

Organization

In the ninth year of contract operation, the NIAC staff were located at the NIAC Headquarters office in Atlanta, Georgia, the Washington, D.C. area, the greater Boston area, and the Chicago area. Since NIAC is an Institute of the Universities Space Research Association (USRA), the NIAC Director reported to the President of USRA.

USRA used many methods in its management of NIAC to ensure NASA is provided with quality service at a reasonable price. Approximately 70% of the funds provided by NASA for the operation of NIAC were used for funding advanced concepts. USRA referred to the remaining 30% of the NIAC budget as NIAC operations costs. Three general management processes and/or methods were employed to provide a comprehensive and cost-effective, advanced concepts development program for NASA. First, USRA used a proven solicitation and peer review process to solicit, evaluate, and select proposed advanced concepts. Once new concepts are selected for funding, USRA employed the second phase of its acquisition management approach, which is to award a grant or contract to the selected organizations. To accomplish this, USRA used its government-approved purchasing system. USRA personnel working this aspect of the acquisition process are guided by the USRA Procurement Manual, which is modeled from the Federal Acquisition Regulations. After the appropriate contractual instrument was awarded, USRA moni-



The NIAC Organization Chart

tored overall performance against the respective proposed budget and concept development milestones through bi-monthly reports from the principal investigators covering technical, schedule, and budget status.

ANSER, through a subcontract from USRA-NIAC, brought unique knowledge and expertise to the NIAC program by providing technical and programmatic support to the operation of the Institute. ANSER's participation in the operation of NIAC enabled the Institute to have access to significant resources developed over decades of support to the government through the Department of Defense (DoD). ANSER provided a means to stay aware of innovative DoD and Homeland Security (HS) activities relevant to NASA and NIAC. ANSER has a long association with U.S. military aerospace activities, DoD research facilities, and the Defense Advanced Research Projects Agency (DARPA). ANSER's Homeland Security Institute maintains a close working relationship with agencies and organizations involved in homeland security. This facilitated the introduction of NIAC Fellows and concepts to the relevant DoD and HS communities. At ANSER's initiative, several NIAC Fellows have presented their research via invited talks in classified settings (e.g., through an NRO speaker's forum). ANSER also supported the operation of the Institute as an electronic virtual entity.

As a corporate expense, the NIAC Science Council was formed to oversee the operation of NIAC on behalf of the relevant scientific and engineering communities. The Council was composed of a diverse group of thinkers, eminent in their respective fields, and representing a broad cross-section of technologies related to the NASA Charter. The Council had a rotating membership with each member serving a three-year term. The USRA Board of Trustees appoints all Council members. The membership of the Science Council in NIAC's final year is shown in Table 14.

MEMBER	AFFILIATION
Dr. Robert A. Cassanova	*NASA Institute for Advanced Concepts (NIAC) [ex officio]*
Dr. John Cramer	*University of Washington, Seattle*
Dr. Lynda J. Goff	*University of California-Santa Cruz*
General (Ret.) Lester Lyles	*The Lyles Group*
Dr. R. Keith Raney	*Johns Hopkins University*
Dr. Donna L. Shirley - Chair	*President, Managing Creativity*
Dr. James Sinnett	*Aerospace Consultant*
Mr. Parker S. Stafford	*Aerospace Consultant*
Dr. Jack Stuster	*Anacapa Sciences, Incorporated*
Dr. Michael Yarymovych	*Aerospace Consultant*

TABLE 14. Membership of the NIAC Science Council in the final contract year.

Facilities

NIAC Headquarters occupied 2,000 square feet of professional office space in Atlanta, GA. The staff was linked via a Windows 2000-based Local Area Network (LAN) consisting of four Pentium 4 PC's and three UNIX servers. Internet access was provided via a fiber-optic link through the Georgia Institute of Technology network. Other equipment included one EMC AX-100 drive array, one Exabyte tape backup, one Dell Inspiron 7000, one IBM Thinkpad T-21, one IBM Thinkpad T-41, one Epson 765C LCD projector, one NEC MT 1030 LCD projector, one flatbed scanner, one Xerox Phaser 7300DN printer, one HP Color LaserJet 5 printer, one HP LaserJet 4000TN printer, one HP LaserJet 3100 facsimile machine and one Sharp AR405 copier.

The servers used RedHat Linux for their operating systems, Apache for the Web server, Sendmail for the email server, Sybase SQL server for the database, and OpenSSL for Web and email security. The workstations used Windows 2000 for their operating systems, Microsoft Office XP Professional for office applications, Netscape Communicator for email access, and Adobe Acrobat for distributed documents.

Virtual Institute

NIAC envisioned progressive use of the Internet as a key element in its operation. The Internet served as the primary vehicle to link the NIAC office with NIAC fellows, NASA points-of-contact, and other members of the science and engineering communities. The Internet was also the primary communication link for publicizing NIAC, announcing the availability of Calls for Proposals, receiving proposals, and reporting on technical status. All proposals were submitted to NIAC in electronic format. All reports from the Fellows to NIAC and from NIAC to NASA were submitted electronically. The peer review of proposals was also conducted electronically whenever the peer reviewer had the necessary Internet connectivity and application software.

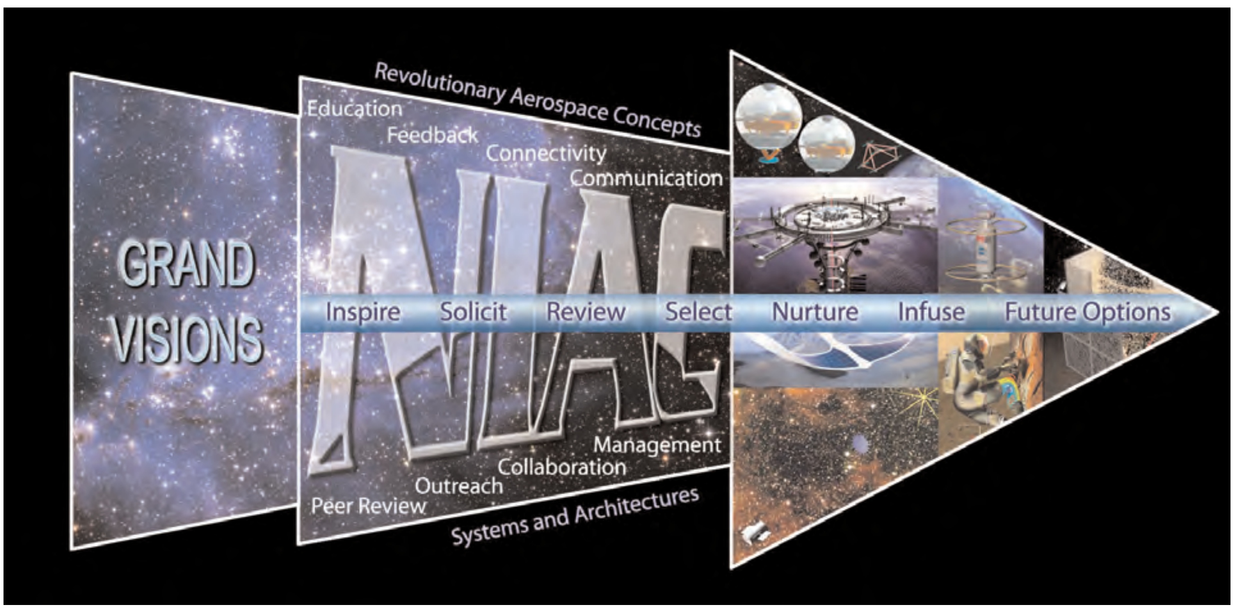
ANSER created and maintained the NIAC web site (http://www.niac.usra.edu) which served as the focal point of NIAC to the outside world. Stored at the web site were general NIAC information, news about NIAC-funded efforts, and the reports and presentations of funded Fellows. The web site was linked from numerous NASA Headquarters and Centers sites. An archived version of the NIAC website will be available after the end of the contract.

The NIAC Web Site Design - http://www.niac.usra.edu.

The NIAC Process

NIAC's role was to provide additional options for consideration by NASA with potentially revolutionary improvement in aerospace performance and the resulting dramatic extension of mission and programmatic goals. NIAC provides a pathway for innovators with the ability for non-linear creativity to explore revolutionary solutions to the Grand Challenges of future aerospace endeavors. The ultimate goal of the NIAC process was to infuse the most successful advanced concepts into mainstream plans and programs.

NIAC followed a process of providing a Grand Vision, Inspiration, Solicitation, Review, Selection and nurturing leading to Infusion in its pursuit of advanced concepts. This process often provided inspiration for enabling technologies and subsystems, scientific discovery and an expansion of the knowledge base.



The NIAC Process

Throughout this process, NIAC engaged in critical ongoing activities for:

- Active involvement with all constituencies of the technical community;
- Collaboration and communication with government, industry and academia;
- Connectivity with technology-oriented organizations;
- Inspiration, education and outreach through the educational community and the mainstream press;
- Supportive management and nurturing of NIAC awardees;
- Feedback from its customers, other agencies and constituencies of the technical community at large.

Grand Visions

During the ninth contract year of operation, NIAC continued to gather, articulate and promulgate Grand Visions that are drivers for revolutionary advances in aerospace, aeronautics and space sciences. Grand Visions inspire giant leaps forward by setting a context for creativity, imagination and innovation. Grand Visions provide a target for Phase I calls and set a high standard for future Fellows and stakeholders inside and outside of the NIAC organization.

This year, in order to continue the discussion of these grand themes, NIAC leadership advanced the themes of Grand Visions in technical outreach presentations, collected suggestions from the technical community, and held a number of one-on-one meetings with high-level agency representatives.

The NIAC leadership integrated the products of these visioning activities into a new statement of Grand Visions included in the CP 07-01 Call for Proposals; this statement also provided the centerpiece for communication about NIAC to various constituencies.

Solicitation

The actual solicitation for advanced concepts was assembled and published by the NIAC staff. The technical scope of the solicitation emphasized the desire for revolutionary advanced concepts that address all elements of the NASA mission. The scope of work was written to inspire proposals in all NASA mission areas.

These revolutionary concepts may be characterized by one or more of the following attributes:

- The genius is in the generalities, and not the details.
- The new idea creates a pathway that addresses a roadblock.
- It inspires others to produce useful science and further elaboration of the fundamental idea.
- It contributes to a shift in the world view.
- It triggers a transformation of intuition.
- Revolutionary paradigm shifts are often simple, elegant, majestic, beautiful and are characterized by order and symmetry.

In general, proposed advanced concepts should be:

- Revolutionary, new and not duplicative of concepts previously studied by NASA,
- An architecture or system,
- Described in an aeronautics and/or space mission context,
- Adequately substantiated with a description of the scientific principles that form the basis for the concept, and
- Largely independent of existing technology or a unique combination of systems and technologies.

The evaluation criteria for Phase I and Phase II concepts were included in the solicitation and are summarized on the next page.

NIAC Calls For Proposals

The NIAC Calls for Proposals were distributed in electronic form only. Under a typical schedule for NIAC operation, NIAC solicited annually for one Phase I and one Phase II. The release of these proposals generally occured in the latter half of the calendar year. In order to be considered for award, all proposals were required to be submitted to NIAC electronically as a .pdf file. Technical proposals in response to Phase I Call for Proposals were limited to 13 pages; whereas, Phase II technical proposals were limited to 25 pages. There was no page limit for cost proposals.

In the ninth contract year, the Phase I solicitation was released. The Phase II solicitation, which was sent only to prior Phase I winners, was not released when it became clear that future funding for the Institute was in question.

PHASE I - 6 months / $50 - $75K	PHASE II - Up to 24 month / Up to $400K
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?	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?

NIAC Proposal Evaluation Criteria

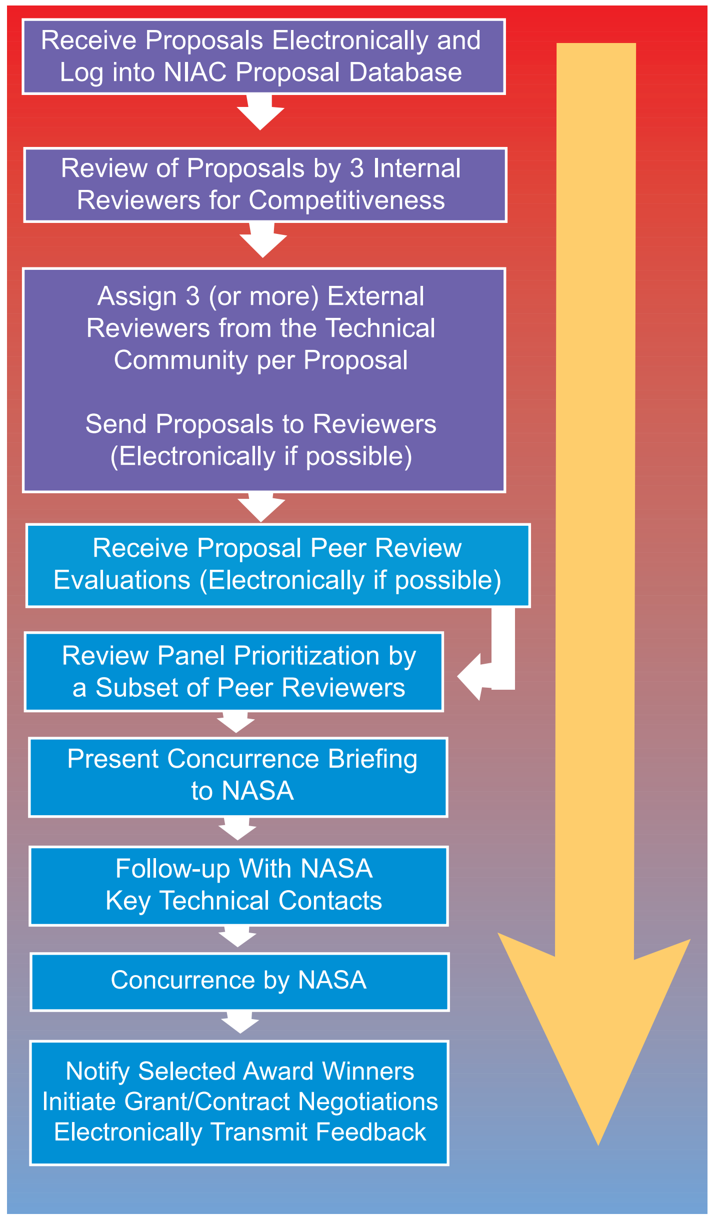
Peer Review

Peer reviewers were selected from the technically appropriate reviewers in the NIAC database. Additional reviewers were recruited as needed to adequately represent the technical emphasis of each proposal. Each reviewer was required to sign a non-disclosure and a non-conflict-of-interest agreement prior to their involvement. A small monetary compensation was offered to each reviewer. The technical proposals and all required forms were transmitted to the reviewer via the Internet, by diskette or by paper copy, depending on the electronic capabilities of the reviewer.

Reviewers were given approximately thirty days to review the technical proposals and return their completed evaluation forms. Each proposal received at least three independent peer reviews. Each reviewer evaluated a proposal according to the criterion stated in the Call for Proposals.

Templates/forms helped to guide the reviewer through the process of assigning a numerical ranking and providing written comments. Only NIAC and USRA staff analyzed cost proposals.

To help ensure that a proposed concept is not duplicating previously studied concepts, NIAC accessed the NASA Technology Inventory Database and other public NASA databases to search for related NASA-funded projects. Throughout NIAC's operation, results of the peer reviews were compiled by NIAC, rank-ordered by a review panel, and prepared for presentation to NASA HQ at a concurrence briefing. However, in the final contract year this process was stopped before the review panel. when it became clear that future funding was in question. Consequently, the next steps in the NIAC review process (Concurrence and Awards) were not taken. However they are described here in order to complete the description of a typical NIAC review and award sequence.



NIAC Peer Review Process

NASA Concurrence

Typically, the NIAC Director presented the prioritized research selections to the representatives of NASA Associate Administrators of the NASA Mission Directorates before the final selection and announcement of awards. Technical concurrence by NASA, required before any subgrants or subcontracts are announced or awarded, was obtained to ensure consistency with NASA's Charter and to ensure that the concept was not duplicating concepts previously or currently being developed by NASA.

Awards

Based on the results of the NIAC peer review, technical concurrence from NASA HQ and the availability of funding, the award decision was made by the NIAC Director. The list of awardees was made publicly available and circulated through NIAC's email lists. The USRA contracts office then began processing contractual instruments to each of the winning organizations. The "product" of each award was a final report, which was posted on the NIAC Web site for public viewing. If requested, feedback based on the peer review evaluation comments was provided to the non-selected proposal authors.

Management of Awards

NIAC required all Phase I (grant) and Phase II (contract) recipients to submit bi-monthly and final reports. All Phase II contractors were required to host a mid-term site visit and to submit an interim report before the end of the first half of their contract. Participants in the site visits included the NIAC Director, invited experts in the technical field of the concept, and NASA representatives. All Phase II Fellows were required to give a status briefing at the NIAC annual meeting. All Phase I Fellows were required to present a poster at the Annual Meeting and give a status briefing at the Phase I Fellows Meeting held near the end of their Phase I grant.

Infusion of Advanced Concepts

The key contract performance metric that was included in the USRA contract with NASA was that 5 - 10% of the selected concepts were infused into NASA's long range plans. After a concept had been developed and nurtured through the NIAC process, it was NASA's intent that the most promising concepts would be transitioned into its program for additional study and follow-on funding. NIAC had taken a proactive approach to this infusion process. In addition to the routine activities to maintain public awareness and visibility for all its funded advanced concepts, NIAC orchestrated the following activities:

- Conducts status and visibility briefings with NASA researchers and managers;
- Provides names of key NASA contacts to NIAC Phase I and Phase II Fellows;
- From the beginning of the Phase II Call for Proposals, NIAC connects Fellows with NASA to provide synergy and optimal program consideration for future follow-on funding by NASA;
- Invites NASA leaders to Phase II site visits to participate in status and planning discussions;
- Encourages NIAC Fellows to publish their work in technical society meetings and technical journals;
- Supports NIAC Fellows to gain NASA testing/evaluation with NASA facilities key to advanced concept verification;
- Extends invitations to key technical leaders in non-NASA agencies and private industry to get keynote addresses at NIAC meetings which create opportunities for NIAC Fellows to interact with these organizations.
- Presents technical briefings to other government agencies such as the Department of Defense and the National Reconnaissance Office to generate awareness of NIAC concepts applicable to their missions.

As a natural consequence of NIAC's open, semi-annual meetings and the posting of advanced concept final reports on the NIAC website, other U.S. government agencies actively pursued contact with selected NIAC Fellows. Some of these contacts resulted in these non-NASA agencies providing funding directly to the NIAC Fellow to continue the development of the concept. As a result, NASA benefitted by leveraging the technical and financial resources of other aerospace-related government agencies.

NASA also had a proactive approach to considering NIAC concepts for further study. The NIAC Director and the NASA COTR collaborated to generate periodic reports on the status of infusion with a particular emphasis on concepts that had a high probability of successful development and should be actively considered by NASA.

We are especially grateful for the funding provided by NASA over the last nine years and for the unwavering support of many exceptional scientists and engineers at NASA Headquarters and the NASA Centers. NIAC's legacy of revolutionary concepts and an atmosphere of scientific creativity will endure.

Robert Cassanova
Diana Jennings
Ronald Turner
Dale Little
Robert Mitchell
Katherine Reilly

APPENDIX A

Descriptions of Enabling Technologies from NIAC

CP 03-01 Studies (Performance Period: October 2004 - September 2006)

TAILORED FORCE FIELDS FOR SPACE-BASED CONSTRUCTION
Narayanan M. Komerath, Georgia Institute of Technology

CRITICAL TECHNOLOGIES

Large-scale direct conversion of solar energy to tunable radio and microwave frequencies is a critical technology. We are developing a concept to automatically build massive structures in space using extraterrestrial materials. We propose to use intense fields in long-wave radio resonators to generate the forces that move the materials into desired wall shapes. The system launch mass from Earth for the construction equipment is currently dominated by the mass of the equipment required to convert broadband solar energy to tunable radio wavelengths. Present-day options for such conversion generally go through an intermediate direct-current step. Other approaches are aimed at micro-scale applications such as cell-phones, where the mass is limited by fabrication and heat-transfer considerations. The scale-up to large power levels is not understood.

1. Electromagnetic Shaping, at all size scales ranging from nano to macro. What is needed is access to large RF facilities that can generate intensive, controlled fields.
2. Robotic sintering of lunar regolith and NEO (Near Earth Object) material.
3. Large tuned conversion devices based on "vacuum" tube technology, where the vacuum of space is used in lieu of a tube.

OTHER TECHNOLOGIES

1. Direct Conversion of sunlight to microwave and/or laser power. Recent Japanese work on Nd-Cr-fiber lasers provides considerable hope that this technology will provide breakthroughs in many space power applications. This technology is directly useful for laser cutting tools to extract NEO (Near Earth Object) resources.

2. Power beaming with high efficiency at the sender and the receiver.

BIO-NANO-MACHINES FOR SPACE APPLICATIONS
Constantinos Mavroidis, Northeastern University

CRITICAL TECHNOLOGIES

1. Bio-nano-robotics. The concept of space bio-nano-robotic systems is based on revolutionary bio-nano-mechanisms formed by protein and DNA based nano-components. Here we focus on assembling these bio nano components to form complex robotic assemblies having advanced properties, such as, distributive intelligence, programming and control. These bio-nano robots would be based on sound design architectures, such as, modular organization and would have the ability to process information.

2. Network based space sensing for planetary environments. The proposed NIAC concept of Networked TerraXplorers (NTXp), is a network of channels containing the bio-nano-robots having the enhanced sensing and signaling capabilities. Using these bio-nano-based robots and utilizing their capabilities of programming and control, we would develop technology to sense the targeted planetary terrain on a very large scale (in order of miles).

3. Radiation responsive molecular assembly. This technology focuses on developing molecular structures which would have an ability to interact with the radiation at the molecular level; characterize its intensity based on energy deposition and relate it to the relative biological effectiveness based on the correspondence established through molecular structure and other properties. Another feature of such a technology is its integration with the current materials at the molecular scale and its widespread presence throughout the material structure.

OTHER TECHNOLOGIES

1. Bio-nano-components. This technology would enable us with a library of bio-nano components having equivalence to the macro robotic components, such as, actuators, joints, sensors etc.

2. Distributive intelligence, programming and control. This technology would give an ability to bio nano-robots to take decisions at nano scale and to store and retrieve information for many useful tasks, such as, sensing another element or condition. Evolvable hardware is one of the technologies which could be benefited by this.

3. Signaling and information flow. This technology would enable development of concepts which would enable the flow of information, its storage and its connection to other bio-nano robotic entities. The signaling of sensed data would be carried out through molecular interfaces to the other bio-nano entities and macro-level devices. The biological signals have to be amplified and converted to electrical signals or chemical signals and have to be processed and stored and this technology would provide us with the same.

4. Dynamics of bio-nano-structures. This technology would enable understanding of key concepts involved in the dynamics of molecular structures. Quantitative and qualitative development of these concepts would help predict the motion, trajectories and other responses of bio-nano-robotic entities subjected to various environments.

DIRECTED AERIAL ROBOTIC EXPLORERS (DARE)

Alexey A. Pankine, Global Aerospace Corporation

CRITICAL TECHNOLOGIES

1. Advanced Balloon Envelope Materials. Advanced balloon envelope materials will be stronger and lighter than existing balloon envelope materials. In the future balloon envelopes will be made out of composite materials - combining layers of materials with desired properties. Future balloon envelopes will be strengthened by fabrics made out of nano-tubes, will be resistant to UV and chemical degradation, and have thermo-optical properties that can be varied "on the fly". These lightweight and strong materials will enable large balloon envelopes for exploration of Mars and Outer Planets, will enable long-duration balloon flights without the need to replenish buoyant gas, and will enable heavier scientific payloads required for comprehensive exploration missions.

2. Lightweight Balloon Guidance and Autonomous Navigation. Balloon guidance technology would take advantage of lightweight material technology and aerodynamic research. For example, an inflatable system made out of nano-tube fabric could be inflated with ambient air. Inflatable wings would harden when exposed to UV radiation or other environmental agents. A balloon guidance system could enable flight path control so that planetary balloons could be directed to scientific targets on the surface or in the atmosphere of a planet. Navigation sensors and advanced algorithms would determine platform location based on observations of the stars and underlying surface features. Autonomous navigation techniques would chart a course to targets or perform high-priority observations without operator commands from Earth. These technologies would enable targeted and adaptive observation strategies envisioned for exploration of the Solar System planets.

3. Reliable and Robust Entry Descent and Inflation (EDI) Systems. Vehicle entry and the initial portion of descent will be very similar to other planetary lander missions. Aerial deployment and inflation of the envelope is desired in order to mitigate the issues associated with ground inflation, i.e. envelope damage in high winds. EDI systems will be able to quickly inflate large balloon envelopes during entry into a planetary atmosphere while maintaining stability and minimizing deployment shocks experienced by the unfolding envelope. For example, EDI could employ cryogenic inflation gas storage to minimize the mass of the gas tanks. EDI systems will enable reliable deployment of aerial platforms in the atmospheres of the planets in the Solar System.

OTHER TECHNOLOGIES

1. Advanced Power Generation and Energy Storage. Advancements in power generation and energy storage are expected to come from development of high-efficiency fuel cells and thin-film solar arrays, and lightweight photovoltaic devices incorporating Quantum Dots technology. These technologies will enable aerial exploration missions in the envi-

ronments with weak solar power sources. They will also enable the use of power hungry instruments, such as radars, on aerial platforms.

2. Compact Science Sensors and Lightweight Dropsondes. Small and lightweight scientific sensors, such as cameras, spectrometers, in situ sensors and others will expand the exploration capabilities of the balloon platforms. Lightweight dropsondes will enable safe delivery of the science instruments to the targeted surface sites on a planet and enable in situ analysis of samples from an overflying aerial platform.

THE PLASMA MAGNET
John Slough, University of Washington

CRITICAL TECHNOLOGIES

A major feature of the plasma magnetic sail is the fact that there has already been a demonstration of the primary technologies in the laboratory at power levels far greater than should be necessary in the space based application. One would however like to see the following developments for space:

1. Better power processing unit. This would include variable frequency (1 to 100 kHz) power supply capable of driving a variable antenna load impedance - one that will be quite low (less than an ohm, typically).

2. Solar wind detection system: It will be critical to be able to gauge the strength and direction of the solar wind for obvious reasons. This will likely need to be a local measurement made by a small satellite of the spacecraft that is positioned outside of the plasma magnet.

3. Guidance systems specifically designed for a thrust vector as complex as what is expected from the solar wind - plasma magnet interaction.

OTHER TECHNOLOGIES

It does not appear at this time that there are any significant technological developments needed, other than those that are mentioned above. The major hurtle for this concept has little to do with technological feasibility. It is convincing NASA or others to take the effort and time to understand the underlying principles, and to realize the revolutionary repercussion to space travel the plasma magnet would have if successfully developed.

ROBOTIC LUNAR ECOPOIESIS TEST BED

Paul Todd, Space Hardware Optimization Technology (SHOT), Inc.

CRITICAL TECHNOLOGIES

1. Pioneer organisms. Planetary ecopoiesis will require living organisms that can withstand extremes of temperature, pressure and humidity while metabolizing actively, at least part-time, as photoautotrophs or chemoautotrophs. Cyanobacteria and certain deep-living autotrophs are candidate pioneer organisms. If they function they can be joined by heterotrophic consumer pioneer organisms like certain bacilli, which can bring early metabolic balance to the pioneer ecosystem.

2. Laboratory ecopoiesis test bed. Before research on extraterrestrial bodies can proceed, research in the laboratory under simulated planetary conditions is required. This requirement is being met by a test bed designed for and dedicated to biological testing. In the case of Mars, a daytime temperature of +26 C and a nighttime temperature down to -130 C are required, along with an atmosphere of Martian composition at 10 mbar. Flexibility of parameters and automated control are important, as the effects of these extremes on pioneer organisms must be taken into account and parameter adjusted accordingly until the effects of the extremes are understood.

3. Efficient and safe miniaturized simulated planetary environments. Challenging thermal problems are associated with creating a portable Mars-like environment that can be distributed among many laboratories and classrooms. If 1,000 teachers and students each study 100 cm2 of simulated regolith under simulated planetary conditions, then 10 square meters of simulated planetary surface could be "under cultivation" at a time using a variety of organisms and approaches. The technical hurdles are heat rejection during the intensely illuminated daytime and cooling during the intensely frigid planetary (or lunar) night and meeting rigid safety requirements.

OTHER TECHNOLOGIES

1. Access to extraterrestrial venues. The above technologies are considered preparatory to research at extraterrestrial venues. All planetary parameters are simulated in the terrestrial test beds except cosmic radiation and gravity. The International Space Station (using centrifuges) and the Moon (using passive thermal control and telemetry) constitute extraterrestrial venues for test-beds where the missing parameters can be included; however, fidelity of other parameters (day-length, atmosphere) would suffer.

2. Novel laboratory information networks. Data synthesis from multiple terrestrial test-beds (and any future extraterrestrial facilities that may emerge) may be required to sum over widely dispersed rare events. Some experiments may take decades. Self-prompting messages and neural networks are only examples of potential technologies that could be utilized to create knowledge from sparse data gathered over many venues.

3. Microbial health assessment. Robust remote sensor technologies that report metabolites, gas composition and other parameters indicative of living matter will ultimately be required as research progresses using terrestrial and extraterrestrial test beds.

CP 05-02 Studies (Performance Period:September 2005 - August 2007)

A DEEP FIELD INFRARED OBSERVATORY NEAR THE LUNAR POLE

Roger Angel, University of Arizona

CRITICAL TECHNOLOGIES

1. Development of a cryogenic liquid of very low vapor pressure and able to accept and hold a mirror-like evaporated surface. Ionic liquids seem to be the most promising candidates, and are known to ~ 150K. Borra has shown that these liquids can be coated with silver with ~90% reflectivity. The infrared sensitivity and science goals would be enhanced by lower temperature, ideally down to 120K.

2. Development of a friction-free superconducting bearing and drive system. Technology for the bearing itself seems to be reasonably well understood. The rotation speed must be controlled by a servo system to less than one part per million, and wobble to a small fraction of the diffraction limit, which is 0.1 arcsec for a 20 m telescope operating at 4 microns wavelength

3. Development of mechanical and control elements with 50 year lifetime. A unique advantage of a lunar observatory is a much longer life than the ~ 10 years of free-flying spacecraft. Technology to minimize radiation damage and optical or mechanical degradation is needed to ensure this lunar potential can be exploited.

OTHER TECHNOLOGIES

Other key aspects are not so much technology, and prerequisites for further development. They are:

1. Dust resistant and durable robotics for transport, construction and excavation are required for construction, deployment and assembly of the telescope. Excavation robotics are being developed for ISRU but will also be required for construction of foundations, landing pads, roads, cable trenches and berms. Durable dust resistant and lightweight excavators with a capacity in the order of 500 kg/hr are required.

2. Infrastructure support. The telescope would not be possible without the Lunar Exploration program. Most important here are the logistic aspects, landing pads, roads, lifting and transportation, perhaps temporary storage of climate sensitive parts and maintenance for robotics and other equipment.

3. Site-test precursor lander. Before a polar telescope mission could be finalized, an in-situ site survey is required. The specific measurements of local and atmospheric dust behavior include soil mechanics, thermal, magnetic and electro static properties as well as an evaluation of the local observation quality. These measurements are to be performed by a small lunar polar lander.

LIVING ORGANISMS FOR BIOREGENERATIVE LIFE SUPPORT DURING LONG-TERM SPACE EXPLORATION

Amy Grunden and Wendy Boss, North Carolina State University

CRITICAL TECHNOLOGIES

1. Plants that can withstand the environments that will be sustained in extraterrestrial greenhouses. A bioregenerative life support system that can withstand the extreme environments of encountered during planetary exploration is essential for long term space exploration. Plants can provide food, purify the air and water as well as supply building materials and pharmaceuticals for human survival; however, terrestrial plants, as we know them cannot withstand the extreme environments including cosmic radiation, rapid and extreme temperature fluctuations, the lack of water and the low pressure that will be encountered in extraterrestrial greenhouses. There is a need to redesign plants to survive these environmental extremes.

2. Earth-based robotic lunar/Martian test-chambers that accurately simulate the environmental conditions on extraterrestrial sites such as the moon and Mars are needed. These test chambers should be designed to accommodate small plant species that have been developed for extraterrestrial environments (e.g. micro-tomatoes and the model system Arabidopsis). The test chambers are essential for evaluating newly redesigned life forms on Earth prior to their deployment in space.

OTHER TECHNOLOGIES

1. Access to extraterrestrial greenhouses: Redesigned plants need to be tested in planetary environments prior to establishing human colonies. Extraterrestrial greenhouses will need to be established to accommodate test plant species.

2. Develop biosensors to monitor the greenhouse conditions and plants redesigned to survive under extreme conditions. Biosensors will be essential to evaluate conditions and to assess plant growth and development, or lack thereof, and to understand the factors contributing to the success or failure of the mission.

THE NEW WORLDS IMAGER

Webster Cash, University of Colorado

CRITICAL TECHNOLOGIES

1. Traveling Spacecraft. For the starshades to work they must travel thousands of kilometers between target alignments using a great deal of fuel. High delta-v systems with low mass are needed.

2. Station-keeping. Once in position, the spacecraft must hold position to a few meters relative to the line of sight to the celestial sphere. Automated alignment sensing and position correction schemes are needed.

3. Large, Shaped Deployables. The Starshades are 30 to 100 meters in diameter. To fit the size and mass constraints of launch, they must be made from large, thin sheets. Technologies for deployment to millimeter class precision in space are needed.

4. Low Scatter Surfaces and Edges. Starshades must be very dark. Some part of their edges will invariably be in sunlight. Techniques for minimizing diffraction and scatter on the edges of the deployable sheets need development.

OTHER TECHNOLOGIES

1. Precision Formation Flying. Starshades can make exoplanets visible to telescopes. If the telescopes are held in an interferometric array, then actual photographs of Earth-like planets can be captured. This will involve developing precision formation flying of the telescopes over hundreds of kilometers of space.

2. Low Noise Interferometers. Low noise detectors and efficient beam combiners can improve the performance of the system and lower the cost.

3. Large Deployable Telescopes. Observations of exoplanets can be greatly enhanced by large, diffraction-limited telescopes operating in the visible band. Practical telescopes of 10m diameter involve deployable main mirrors.

MICROBOTS FOR LARGE-SCALE PLANETARY SURFACE AND SUBSURFACE EXPLORATION

Steven Dubowsky, Massachusetts Institute of Technology

CRITICAL TECHNOLOGIES

1. The development of micro fuel cells (mm scale). Power for small robotic systems, for which solar cells are not feasible, such as in our concept, is critical. An environment with high efficiency cell technology working temperatures compatible with sensors, electronics would have a major positive impact on a wide range of systems.

2. The development of low weight high capacity hydrogen and oxygen storage elements. These are essential to the fuel cell concept.

3. The development of high performance very light weight actuators. Again, this technology is currently a key road block to future space robotic systems. This aspect is a major focus of our work.

OTHER TECHNOLOGIES

1. The development of micro-sensors for planetary exploration. The development of sensors that are very small, low power and robust are essential for our microbots.

2. Algorithms for group behaviors for teams of planetary robotics systems where the individual team members have limited capabilities. Our microbots would need these algorithms to optimally explore large areas with limited mobility and sensor ranges.

3. New non-line of sight communication technology. This would help our subsurface communication between our microbots when they function in planetary caves.

INVESTIGATION OF THE FEASIBILITY OF LASER TRAPPED MIRRORS IN SPACE

Elizabeth McCormack, Bryn Mawr College

CRITICAL TECHNOLOGIES

1. Nanotechnology design and fabrication to produce the ~ 10^{15} particles required for an orbiting laser trapped mirror. Particles need to be highly uniform in shape and size (in the range of 0.1-1.0 micron). Particle shape and material composition need to be designed to couple optimally to the trapping field and have high reflectivity over a broad spectral range around the observing wavelength. Possibilities for engineering "structures" with the potential to dissipatively damp the relative motion of the trapped particles are also of interest.

2. Extremely stable, long coherence-length, high-power lasers suitable for continuous use on orbit for periods of 3 to 5 years will be critical. In addition to total laser output power, the efficacy of optical binding and optical trapping to create optical matter will benefit from the development of new methods for shaping the gradients of electromagnetic fields. Steeper gradients have the potential to reduce laser power requirements and increase mirror stability.

3. Improved sunshield technology affording both passive cooling of the mirror particles to less than 30 K at L2 and a very high level of protection from solar outflow and magnetic fields. The stability of the mirror will be determined by the balance between the strength of the optical fields present and the combined affect of the particle temperature, the degree to which the particles become charged and the degree to which they couple to magnetic fields.

OTHER TECHNOLOGIES

1. Orbital energy management, communication, station-keeping, and other infrastructure to give us a range of innovative orbit options. We will be seeking orbits that minimize zodiacal heating, in order to achieve a mirror temperature as close as possible to the theoretical limit of 3 K, while still remaining close enough to the Sun to power the lasers.

2. Technology for neutralizing accumulated charge on the delicate grid of particles comprising the trapped mirror surface. Charges that accumulate on the mirror particle surfaces have the potential to counteract the optical binding forces.

CP 06-02 Studies (Performance Period: September 2006 - August 2007)

A CONTAMINATION-FREE ULTRAHIGH PRECISION FORMATION FLIGHT METHOD BASED ON INTRACAVITY PHOTON THRUSTERS AND TETHERS: PHOTON TETHER FORMATION FLIGHT (PTFF)
Young Bae, Bae Institute

CRITICAL TECHNOLOGIES

1. Engineering Space Flight-Ready Photon Thrusters. The proof-of-principle of photon thrusters, the most critical components to implementing PTFF, has recently been demonstrated in the laboratory environment with the use of COTS successfully. Further improvements in the power and thermal managements of photon thrusters are essential to engineering the mission-specific flight-ready PTFF systems with the use of custom-made optical components, power systems and thermal management systems.

2. Integration of Photon Thrusters with Precision Interferometric Ranging Systems. We have recently made a major progress in conceptually developing and designing the highly compact and power efficient integrated system of photon thrusters and precision interferometric ranging systems. Laboratory demonstration and engineering of the flight-ready integrated system are thus required. For visual optical space-borne applications, the accuracy requirement for the interferometric ranger is in the order of 25 nano-meters, which can be achieved straightforward with the existing technologies. Further development of the integrate system towards UV, XUV, and x-ray applications will require progressively increasing accuracy requirement, and the required technologies should thus be investigated and developed.

3. Integration of Tether Systems with the Optical Systems. The implementation of PTFF requires novel integration methods of tether systems with the optical systems that are the integrated photon thruster systems and interferometric ranging systems. This engineering development will require elaborate computer simulation studies first to investigate the optimum space-borne PTFF structures, followed by sub-scale and full-scale in-space demonstrations.

OTHER TECHNOLOGIES

1. Overall Dynamics Control System. In PTFF structures, the environmental perturbation from any direction will be distributed into the 1-D force sub-structure between paired spacecraft. In the overall 3-D PTFF system the lateral shifting or bending of sub-component 1-D systems is a major concern. The control dynamics simulation and computation

studies of this aspect should be performed to develop efficient 3-D PTFF control systems, followed by sub-scale and full-scale in-space demonstrations.

2. Target alignment, Scanning and Retargeting Technologies. The technologies of target alignment, scanning and retargeting should be developed for PTFF. Small angle alignment and scanning can be achieved by adjusting the relative baseline distances of subcomponent systems. The technologies for such adjustment should be investigated and developed. Major angular alignment of the whole PTFF structure including retargeting may require auxiliary thrusters in addition to the photon thrusters. The selection and integration of the suitable mission-specific auxiliary thrusters for such maneuverings should be investigated and developed.

3. Launch and Deployment Technologies. The technologies for the launch and initial deployment of PTFF systems have to be developed. First, computer simulation studies should be performed to identify an ideal engineering solution for this issue. Launching the PTFF structure can be achieved in a single delivery or multiple deliveries. For the method involving multiple deliveries, the system should be assembled first before deployment. We have preliminarily shown that the photon thrusters can be used for providing the necessary expulsion force required for deployment. However, unrolling the tethers with minimal tether distortion and perturbation is an important engineering issue, and needs further development.

EXTRACTION OF ANTIPARTICLES CONCENTRATED IN PLANETARY MAGNETIC FIELDS

Jim Bickford, Draper Laboratory

The collection and use of antimatter produced naturally in the space environment requires four fundamental advances: an understanding of the natural distribution of antimatter, a highly efficient collector, a stable storage medium, and a mechanism to induce thrust. To this end, we have identified the following technologies that will enable such a system by using a magnetic field to concentrate charged particles which are then trapped in the volume surrounding the vehicle.

CRITICAL TECHNOLOGIES

1. Low mass, high strength, long strand, ultra-high current loops. The generation of a large magnetic field is critical to the success of the program since the field is used to both collect and store antiprotons present in the natural environment. Systems based on current loops with contemporary superconductors are mass prohibitive due to the large size and current loads needed to support stable antiproton trapping and control. High temperature superconductors with current densities much greater than 1010 A/m2 at 90K and L>100m will enable far more compact and mass efficient systems. Beyond this, the full scale implementation of a plasma magnet to generate the bulk field is also desirable and needs to be demonstrated at full scale.

2. Radiation tolerant in-orbit power source. The particle collection system is required to operate in a high radiation environment. Though the magnetic field will shield the system from much of the incoming flux, a radiation tolerant power source is necessary to generate the initial current before the field is fully established. The intrinsic energy contained in the field dictates that a high power source be available in order to charge the system in a reasonable time. A space qualified nuclear reactor with a power output of at least 100 kWe is desirable to ensure success.

3. Compact mass spectrometer placed in highly eccentric orbit. In situ measurements of antimatter fluxes in the Earth's radiation belt and around the Jovian planets have not been made. The models developed as part of this program should be verified by direct experimental evidence before significant resources are committed to implementing a full system. Current orbital missions do not have the spatial and/or property coverage to characterize the relevant environment. A compact mass spectrometer capable of differentiating protons, antiprotons, electrons, and positrons should be developed and flown in a highly eccentric orbit with an apogee of at least 6 RE to completely characterize the antiproton and positron environment. Such a system will also contribute greatly to the knowledge of the radiation belts and the interaction between the Earth's magnetosphere and the Sun.

OTHER TECHNOLOGIES

1. Antiproton catalyzed fission/fusion engine. Nanograms to micrograms of antiprotons do not have enough intrinsic energy to propel a spacecraft to high velocities when relying exclusively on the annihilation products. Instead most by energy from conceivable near term antiproton propulsion systems rely on using the antiprotons to induce fission reactions. The antiprotons catalyze nuclear reactions in sub-critical fissile material to propel the vehicle by leveraging the nuclear material in a safe and controllable manner.

2. Passive cooling systems. Reduced mass multi-layer thermal blankets for passive temperature control of large structures with $T_{max} < 90K$ at 1 AU will improve the overall mass efficiency and reduce requirements on the high temperature superconductors wires used.

3. Affordable lift. The final system will be relatively massive. Reducing the cost to orbit with new affordable heavy lift options, though not strictly required, will improve overall feasibility.

LORENTZ-ACTUATED ORBITS (LAO): ELECTRODYNAMIC PROPULSION WITHOUT A TETHER

Mason Peck, Cornell University

CRITICAL TECHNOLOGIES

1. Lightweight self-capacitive materials and structures. The charge-to-mass ratio of an electrically charged spacecraft is limited by the need to hold this charge on the surface of a conductive body. To enable extraordinary missions such as propellantless earth escape during a year's maneuvering, LAO spacecraft require self-capacitive structures that can hold at least 5 C/kg. This charge density may be achieved volumetrically within an insulating material, on the surface of some subtly designed conductive body, or perhaps within a confined magnetic field. Whatever the solution, the self capacitance must be high and any charge deposited by a planetary plasmasphere must not permanently neutralize the charge on the capacitor.

2. Compact self-capacitive materials and structures. When subject to plasma currents from the environment, the capacitive body must emit charged particles to remain at the desired potential. Compact capacitors reduce ram current collection, saving power and reducing the overall mass required to achieve LAO performance. Compact compacitors also are vastly preferable to the long, unwieldy structures possible via current technology because compactness enables more agile spacecraft and opens up more general attitude motions of such spacecraft. A target charge density of about 1-10 C/m3 keeps the Lorentz capacitor structure within the length scale of currently envisioned space systems.

3. High-Voltage Power Systems to Maintain High Spacecraft Charge. While the available power per se also limits the performance of an LAO spacecraft, the potential that the capacitor can achieve drives the performance most directly. A power supply that offers 10 kW at 40 kV enables some low-thrust missions. Power in the MV range enables high-thrust missions. One possible solution for such a technology is to exploit nuclear fission or decay processes that expel charged particles directly. Adapting nuclear power systems already in development for this special purpose would realize much higher efficiency because merely expelling the charged particles requires no thermionic energy conversion, no Stirling or Brayton cycles, etc. So, the energy of fusion or decay is used directly.

OTHER TECHNOLOGIES

1. Materials Compatible With High-Potential Environments. An extreme, speculative solution for LAO technology involves using alpha-emitting isotopes on the surface of diaphanous space structures to establish a potential of 5.3-5.6 MV. Materials that comprise the capacitive structure must withstand this environment.

2. Materials with High Photoelectric Currents. An LAO spacecraft can exploit natural processes such as photoelectricity for charging, but this approach is effective only if the material that emits electrons does so very efficiently. Rather than indirectly absorbing solar power through solar cells and emitting current, what type of material can be exposed to sunlight (and/or other energy sources in the space environment) to emit charged particles at high kinetic energy? The energy of these photoelectrons (or other particles) ought to be above 10keV if the material is to be useful for LAO.

AN ARCHITECTURE OF MODULAR SPACECRAFT WITH INTEGRATED STRUCTURAL ELECTRODYNAMIC PROPULSION (ISEP)

Nestor Voronka, Tethers Unlimited, Inc.

CRITICAL TECHNOLOGIES

1. The key enabling technology for an electrodynamic propulsion system is a plasma contactor that enables efficient collection and transmission of current between the ISEP system and the ambient space plasma. This contactor must be able to emit electrons and ions at low power consumption levels, and utilize minimal consumables to configure the system for highest specific impulse (Isp) and thrust-to-power ratios. The leading technologies for these contactors include field-emissive cathode arrays for electron emission, liquid-metal ion sources, and solid expellant bi-polar contactors, all of which require further research development to make them available for electrodynamic propulsion applications and flight missions.

2. As the ISEP system is fundamentally an electric propulsion system, highly efficient energy collection, processing and storage modules are critical to overall system performance. For energy storage, and in particular high current pulse applications, demonstrations have suggested that flywheels are a leading potential solution. Additional benefits of this technology include long-life and capacity for high depth of discharge, however additional technology maturation work is required.

3. The resistive losses in the ISEP boom elements can be substantial, especially at the high current levels planned for the system. High current density, high temperature superconducting wire will further increase the performance of the ISEP system. Sufficient superconducting materials have been demonstrated in the lab environment, so the important technology advances here will be in the manufacturing and production of superconducting wires.

OTHER TECHNOLOGIES

1. Control laws for low-thrust propulsion systems have seen some development, and in particular for orbit-raising applications where solar eclipsing has been taken into consideration. Further development is required to develop control laws for electrodynamic propulsion systems that rely on Lorentz force thrusting as the thrust direction and magnitude is highly dependent on the ambient magnetic field. Laws that optimally control the magnitude of current in the multiple ISEP structures (both gravity-gradient and others) and therefore direction of thrust need to be developed.

APPENDIX B

CP 05-02 Awardees

A Deep Field Infrared Observatory Near the Lunar Pole
Roger Angel, University of Arizona

This proposal is to explore the feasibility and scientific potential of astronomical telescopes made with 20 – 100 m liquid primary mirrors at the South Pole of the Moon. Such telescopes, equipped with imaging and multiplexed spectroscopic instruments for a deep infrared survey, would be revolutionary in their power to study the distant universe, including the formation of the first stars and their assembly into galaxies. Already at 20 m diameter, the resolution would be 3 times higher than the James Webb Space Telescope (JWST), and, by integrating for a year, objects 100 times fainter could be reached. Liquid mirror technology is ideally suited for this application, requiring only a gravitational field and uniform rotation to maintain exquisitely accurate surface figure over very large aperture. It's far simpler that the conventional alternative, a mirror made from solid surface segments, requiring mechanical and optical alignment maintained to 30 nm tolerance. On Earth, liquid mirrors are limited to ~ 6 m size by wind and are subject to atmospheric absorption and distortion. The Moon, though, provides the required gravity field with no such limitations. At the poles, the zenithpointing mirror sees the same extragalactic field of view at all times, allowing very deep imaging and spectroscopy by integration for years on the same region. Simple radiation shielding can be used to cool the instrument for high infrared sensitivity, and solar power is available continuously.

The goals of this study are to understand better the scientific potential, to explore the "tall tent poles" that must be overcome to make such a telescope practical, and to explore the value of human presence for erecting the telescope and for occasional instrument upgrades. This study will thus be of value in developing scientific exploration goals for NASA's planned return to the Moon.

Redesigning Living Organism to Survive on Mars
Wendy Boss and Amy Grunden, North Carolina State University

Providing life support for human exploration is a major challenge as we venture to Mars and beyond. Our hypothesis is that we can revolutionize life forms by selectively expressing in plants extremophile genes that will collectively enable functional life in inhospitable environments. For our phase I proposal, we demonstrated for the first time that an archaeal gene, superoxide reductase from Pyrococcusfuriosus, could be transcribed and translated in a model eukaryotic system to produce a functional enzyme which retained the properties of the original archaeal protein. In our phase II proposal, we will extend our studies to the whole plant and will include a suite of genes from the P. furiosus reactive oxygen species (ROS) detoxification pathway that together will confer resistance to oxidative stress. Furthermore, we will increase reduced glutathione by introducing the glutathione reductase (GR) gene from a psychrophilic extremophile Colwelliapsychrery-thraeain order to address a major problem facing Earth based organisms on Mars, stabilizing protein structure during the rapid changes in temperature that will be encountered even in enclosed environmental chambers. We will cross plants producing the heat stable ROS and cold functional GR enzymes to generate a hybrid plant tolerant of extreme environments, including cold, drought, heat and radiation. After each T4 generation transgenic plant has been produced, the plants will be distributed to NASA-funded labs for more complete physiological testing in space environments. In addition, we will work with investigators to introduce the genes into breeding programs to revolutionize breeding programs for crops to be grown in space. Finally, our road map includes working with an honors undergraduate class to investigate the use of novel genetic approaches to generate plants resistant to radiation damage to DNA.

The New Worlds Imager
Webster Cash, University of Colorado at Boulder

We propose a two year, Phase II study of the New Worlds Imager concept. In Phase I we showed how the concept of a starshade has the potential to make studies of planets around other stars routine, without technical heroics. The starshade is a large, deployable sheet on a separate spacecraft that is flown into position along the line of sight to a nearby star. We showed in Phase I how a starshade could be designed and built in a practical and affordable manner to fully remove starlight and leave only planet light entering a telescope. The simulations are very exciting, showing we can detect planetary system features as fine as comets, perform spectroscopy to look for water and life signs, and perform photometry to search for oceans, continents, clouds and polar caps. We also show how a true Planet Imager can be made from two starshade apertures and a fifth spacecraft carrying an interferometer. In Phase I we showed through simulation that features as fine as 100km across can be detected and mapped from 30 light years with this New Worlds Imager.We propose to continue the study of the New Worlds concept into Phase II. We will fully define the approaches to building starshades and telescopes. This will include identification of materials, deployment methods, target acquisition techniques, thrusters for holding spacecraft alignment, available launch vehicles and ideal orbits. The study will also include a laboratory demonstration of high contrast using a shaped pupil. We expect to solve all the remaining problems and publish our results. We will continue the studies into a full road map to the New Worlds Imager.

Microbots for Large-Scale Planetary Surface and Subsurface Exploration
Steven Dubowsky, Massachusetts Institute of Technology

This proposal presents a new robotic planetary exploration concept based on the deployment of a large number of small spherical mobile robots (microbots) over vast areas of a planet's surface and subsurface, including structures such as caves and near surface crevasses (see Figure 1). This strategic exploration architecture can enable extremely large scale, in situ analysis of scientifically interesting properties thus enabling a new paradigm for Solar Systemwide exploration, mapping, and scientific study. This approach represents an important alternative or augmentation to current rover and lander-based planetary exploration, which is limited to studying small areas of a planet's surface at a small number of sites. The proposed approach is also distinct from balloon or aerial missions, because it allows in situ, direct contact measurements. Once developed, such units can be custom tailored to specific mission targets with minimal additional cost. In the proposed mission concept, a large number (i.e. hundreds or thousands) of 10 cmscale, subkilogram microbots would be widely distributed by orbital craft, from aerial platforms, from a lander, or even by lunar or Mars astronauts. The microbots employ hopping, bouncing, and rolling as a locomotion mode to reach scientifically interesting features in very rugged terrain. The units will be powered by high energy density polymer muscle actuators, and equipped with a suite of miniaturized instruments selected for each specific mission, e.g., imagers, spectrometers, or chemical detection sensors. Multiple microbots will share information and cooperatively analyze large portions of a planet's surface or subsurface. Numerous units allow for considerable mortality without jeopardizing the mission. In this proposed Phase II study, a detailed microbot mission scenario will be developed for a planetary reference mission suite. Enabling technologies for actuation, power, sensing, and communication will be surveyed. Fundamental research on muscle actuators and microbot mobility mechanisms, and efficient coordination algorithms will be developed. A small number of prototypes will be produced and tested in field conditions in New Mexico. Work will be conducted by a multi-university team of engineers and scientists at MIT, New Mexico Institute of Mining & Technology, and Stanford.

Investigation of the Feasibility of Laser Trapped Mirrors in Space

Elizabeth McCormack, Bryn Mawr College

The Laser Trapped Mirror (LTM) was first proposed by Antoine Labeyrie [1] as an innovative way of producing large lightweight optics in space. Labeyrie suggested using laser light to structure standing wave fringe surfaces in the space between counterpropagating laser beams. With appropriate optics, these fringe surfaces might have the shape of a family of parabolic sheets and the same principles that underlie optical traps (optical tweezers, for example), could, in principle, permit trapping of atoms, molecules or larger particles along the standing-wave (fringe) maxima. Tuning the laser wavelength in single mode from red to blue in successive saw-tooth steps would permit collection of the trapped particles into a single parabolic sheet, the zero fringe. The result of this process is a reflective parabolic surface, of almost arbitrary size, which could serve as the primary of a large telescope. A 100-nm thick, 35-meter diameter mirror would require less than 100 grams of material. Development of low mass, large optics is important to many areas of space research, but it is of particular interest to astronomers, especially those concerned with detection of extra-solar terrestrial planets. Here, we propose a combined laboratory and analytical/modeling investigation of the properties of a Laser Trapped Mirror with the aim of determining whether the LTM is a practical solution to the problem of building large, low mass optical systems in space. Specifically, in this phase 2 effort our goals are to:1) demonstrate and characterize mirror behavior for the case of a small LTM, performing the trapping in liquid, 2) develop and exercise the algorithms and modeling tools required to understand LTMs, 3) combine laboratory measurements with a plausible particle design and trapping model to produce estimates of mirror stability and laser power requirements in a vacuum environment, and, 4) assure ourselves that the space particle and fields environment is not prohibitively severe.

APPENDIX C

CP06-01 Awardees

Development of a Single-Fluid Consumable Infrastructure for Life Support, Power, Propulsion, and Thermal Control
David Akin, Space Systems Laboratory, University of Maryland

This proposal describes the concept of a highly innovative architecture of interrelated systems including portable life support systems for EVA suits, power supplies for rovers and robots, propulsion for in-space maneuvering and local surface ballistic hops, and thermal control systems, all based on the use of a single high-density room-temperature liquid consumable: an aqueous solution of hydrogen peroxide (H2O2). In this concept, the catalytic dissociation of H2O2 into water and oxygen provides electrical energy; the oxygen is used in life support systems for breathing, and the water for sublimation cooling in deep space and on the lunar surface. Due to the atmosphere and colder temperatures on Mars, the waste heat from the H2O2 dissociation can be utilized to provide selective warming of the space suit or robot components. Expansion potentials for this system are discussed, including the use of waste heat to regenerate metal oxide-based CO2 scrubbers or to heat an EVA suit in extreme conditions such as the lunar poles, external supply of H2O2 from a rover vehicle for extended EVA surface operations, and the provision of an integrated hot-gas H2O2 propulsion system for in-space activities or short ballistic transports on the surface of the moon or Mars. Due to the complex and life-critical nature of the life support function, the focus of the proposed Phase I investigation will be the detailed design and analysis of a hydrogen peroxide portable life support system (HyperPLSS) system for EVA suits, in parallel with the design of synergistic applications of the H2O2 technology in surface rovers, propulsion systems, and thermal control systems. Phase 2 will focus on the breadboard development of a single-fluid H2O2 PLSS system, and testing of the system against the analysis tools.

Practicality of a Solar Shield in Space to Counter Global Warming
Roger Angel, Steward Observatory, University of Arizona

A solar shield 2000 km diameter at L1 would deflect enough sunlight to counteract global warming. Such a space-based solution might become an urgent priority, worth trillions of dollars if abrupt climate failures appear otherwise inevitable. We propose to identify near-term research and space missions needed to understand whether a shield could be completed within a few decades at an affordable cost. New optical strategies and concepts for deployment as a cluster of free-flying units will be developed, to minimize mass. In this way launch from Earth may be affordable, using advanced, high-volume methods with high energy efficiency.

Self-Deployed Space or Planetary Habitats and Extremely Large Structures
Devon Crowe, Physical Sciences, Inc.

We propose an approach for constructing compact payloads with low mass that can erect very large and strong structures. This technology would enable payloads small enough to launch that can become self-contained orbital habitats, large buildings on planetary surfaces, or other large structures that require significant strength. Our approach uses inflated bubble structures and suspended films which are then made rigid. The mass density of the deployed structures is far below previous technologies such as inflated balloons.

Primary Objective Grating Astronomical Telescope
Tom Ditto, DeWitt Brothers Tool Company

We propose a new architecture for astronomical telescopy with objective gratings. Unlike a slitless objective grating telescope, we include a slit and a spectrometer in a secondary that is configured at grazing exodus. Resulting anamorphic magnification produces a ribbon shaped aperture that can achieve kilometer scale along one axis. The telescope could disperse light from all objects within a 1° x 40° field-of-view with sub-Ångstrom resolving power and milliarcsecond spatial resolution across the wider angle. Taking advantage of the earth's rotation, a ground-based version can make observations with no moving parts. The secondary spectrometer uses a novel data reduction algorithm that can assemble millions of spectrograms simultaneously. To defeat wind pressure, the primary can be seated flatly on ground level with the secondary sheltered below ground. Lunar observatory deployment and operation are simplified, because the flat primary is lightweight, and as a staring instrument it has no moving parts. In space deployment, the thin primary lends itself to construction from flat gossamer membranes. The science drivers are broad - spanning most astronomical observational arenas, but in terms of NASA's road map this new telescope could be a life planet finder. In terms of NASA's core service programs, special features of this design could be exploited to survey for millions of small objects in near earth orbit.

Reduction of Trapped Energetic Particle Fluxes in Earth and Jovian Radiation Belts
Robert Hoyt, Tethers Unlimited, Inc.

The energetic radiation particles trapped by the strong magnetic fields of the Earth, Jupiter, and other planets present a tremendous challenge for human and robotic exploration and development of space. These energetic particles cause biological damage in humans and constant degradation in electronics and other materials used in spacecraft. The current methods for dealing with the orbital radiation environment are to limit long-duration manned missions to low-altitude orbits below the intense regions of the Van Allen belts, to protect orbital facilities with heavy shielding materials, to minimize the duration of extravehicular activities of personnel outside the shielding of orbital facilities, and to utilize heavy, expensive, and low-performance electronics and other components in spacecraft systems. These measures, however, are insufficient to ensure the safety and performance of human and robotic components of a sustained program of exploration and development of space. The proposed effort will evaluate the feasibility of actively reducing the fluxes of energetic particles trapped by the magnetic fields of Earth and Jupiter utilizing high voltage orbiting structures. Recent analyses of scattering of energetic electrons by highvoltage structures have indicated that a technically and economically feasible system could rapidly reduce particle fluxes in man-made radiation belts. This project will investigate application of this concept to elimination of the naturally-occurring Van Allen belts. Remediation of the Van Allen belts could dramatically reduce the risks and costs associated with long-duration manned missions in Earth and Jovian space. Additionally, by reducing the rate of degradation of solar panels and electronics in these regions, it could significantly improve the performance and economic viability of systems such as solar-electric propulsion tugs for lunar missions and solar power satellites. The proposed effort will develop system concepts for Earth and Jovian radiation belt remediation, investigate the potential environmental effects of such an effort to reduce the natural radiation belts, and develop strategies and designs for validating the concept feasibility through experimentation and simulation.

In-Orbit Assembly of Modular Space Systems with Non-Contacting, Flux-Pinned Interfaces
Mason Peck, Cornell University College of Engineering

The familiar forces that act between objects at a distance--the Coulomb force, magnetism, and gravity--vary with the inverse square of the distance between objects (i.e. the potential energy varies with the inverse of distance). Technological applications of these forces are limited by Earnshaw's Theorem, which states that no combination of such forces can result in stable separation of objects in all six degrees of freedom. Active control is typically required, as in the case of magnetic bearings. One way around Earnshaw's theorem is to take advantage of the surprising physics of high-temperature flux-pinning superconductors. These materials resist being moved within magnetic fields, resulting in stable relative orientation and position of some number of bodies at finite distances. Furthermore, they do so without power and with no need for active feedback control. The proposed study will evaluate the viability of assembling space structures ranging from small spacecraft to large manned space stations from components that are held in place by flux pinning. This general approach to conjoining mechanical parts without mechanical connection offers the promise of revolutionizing in-orbit construction. The proposed non-contacting interface not only solves a host of technological issues, it also opens up a new way of thinking about modular spacecraft. No longer are we required to distinguish among spacecraft subsystems, individual spacecraft, and constellations of spacecraft. Instead, the proposed concept blurs the distinction between modular spacecraft and formation flying, between spacecraft bus and payload, and to some extent between empty space and solid matter. Articulated payloads, reconfigurable space stations, and adaptable satellite architectures are possible without the mass and power typically associated with maintaining relative position and mechanically rebuilding structures. In 2004-2005 we demonstrated the basic principle; on internal funding, we creating some modular building blocks and showed that they can find each other without active control and remain fixed in rotational and translational degrees of freedom at distances on the order of centimeters. The proposed NIAC Phase I study will base its consideration of possible space-system architectures on this recent result and will proceed through the definition of major issues of feasibility. The primary issues include defining the basin of attraction of these modules and what can be achieved if the technology is advanced, how much mechanical stiffness is appropriate and available, and how the superconductors may be kept below their transition temperature in the space environment.

Large Ultra-Lightweight Photonic Muscle Telescope
Joe Ritter, University of Hawaii Institute for Astronomy

Missions such as Terrestrial Planet Imager require lightweight mirrors with minimum diameters of 20 to 40 meters. Unprecedented advances in nanoengineered-materials have recently produced a laser actuated material with controllable reversible bi-directional bending. These Photonic Muscle substrates finally make precision control of giant apertures possible. Membrane mirror shape and dynamics can now be precisely controlled with low power light. This enables innovative missions for imaging the cosmos, resolving spectral and spatial details of exosolar planets and searching for life, including evidence of Earth's Origins, while substantially reducing mass, launch and fabrication costs. Missions like TPI will now be feasible.

Bio-Electric Space Exploration
Matthew Silver, Intact Labs, LLC

The need for electrical power drives almost every aspect of space exploration missions, severely impacting location, duration, and scientific return. Existing power generating technologies for exploration are based on solar, nuclear, or low-efficiency chemical sources. However, myriad biological processes on Earth generate electricity at ultra-high levels of efficiency with power-to weight ratios that would be unimaginable with current space technology. Batteries and power generation technologies based on scaled biological processes hold the potential to create a paradigm shift in human and robotic space exploration, affecting everything from space suit design to remote base design to the design of space-craft and robotic probes. For example, proteins such as Prestin in the inner ear, or Mechano-sensitive ion channels found in almost all living organisms, translate nanometer movements into milli-volts of electricity. Scaling such ultra-sensitive piezo-electric mechanisms opens the door to space suits or bases covered in electricity-generating Power Skins, charged by the Martian winds or the movement of astronauts through the Martian air. In a different direction, microorganisms such as Rhodoferax have been shown to convert Glucose or waste into electric potential, leading to the possibility for microbial fuel cells. One can imagine modifying such bacteria for integration in Electric Greenhouses that produce electricity and food while treating waste on space vehicles or exploration bases. Development of these ideas entails working at the intersection of synthetic biology, space systems design, space operations, and electrical engineering. For Phase I we will catalogue myriad potential bio-electrical processes and space applications, down-select promising candidates, create a customized bio-sensor using known methods to measure electric-generation potential and begin initial testing of candidate solutions. Phase II would then focus more directly on a few specific organisms and applications with highest potential, resulting in more detailed wet-laboratory work extracting, testing, and scaling such processes, as well as detailed conceptual designs and computer models of space systems architectures based on such methods.

Plasma Magnetic Shield for Crew Protection
John Slough, University of Washington

Exposure to the energetic particles associated with solar energetic particle events and galactic cosmic rays are known radiation hazards for human exploration. Material shielding and superconducting solutions add substantial mass to spacecraft and provide shielding over very limited areas. It is proposed here to provide the shielding by making use of ambient low density plasma ejected from the spacecraft that supports the large scale currents required to provide sufficient magnetic flux to deflect the energetic particles. Based on laboratory results, such a closed magnetic configuration can be produced by force-free currents and is referred to as the plasma magnetic shield.

Extreme eXPeditionary Architecture (EXP-Arch): Mobile, Adaptable Systems for Space and Earth Exploration
Guillermo Trotti, Trotti & Associates, Inc.

The Extreme eXPeditionary Architecture (EXP–Arch) proposes self-mobilized, transformable systems that interrelate in ways never before envisioned. EXP–Arch combines robotic systems, deployable lightweight structures, intelligent materials, and mathematical origami techniques to revolutionize human and machine exploration. A paradigm shift for exploration is proposed by creating an architecture, or suite of systems, based on highly mobile, quickly deployable and retractable systems. EXP–Arch is an adaptive exploration architecture for extreme environments (space and earth inaccessible locations) utilizing multi-functional, inflatable, and transforming system components. EXP–Arch attempts to better understand human-robotic synergies during exploration, and offers an educational initiative entitled, 'Virtual EXP–Arch', for students.

Spacecraft Propulsion Utilizing Ponderomotive Forces
George Williams, Ohio Aerospace Institute

A new spacecraft propulsion scheme is proposed which leverages advances in high-energy particle acceleration via laser-plasma interactions. Ponderomotive forces associated with laser wakefields have demonstrated the potential to accelerate electrons to near-relativistic energies. Different schemes will be investigated which may generate quasi-steady fields for deep-space and manned space missions. Ponderomotive propulsion could revolutionize space travel by providing very high thrust at very high specific impulses.

APPENDIX D

CP06-02 Awardees

A Contamination-Free Ultrahigh Precision Formation Flight Method Based on Intracavity Photon Thrusters and Tethers: Photon Tether Formation Flight
Young Bae, Bae Institute

We proposed a revolutionary nano-meter accuracy formation flight method with photon thrusters and tethers, Photon Tether Formation Flight (PTFF), with the maximum baseline distance over 10 km for next generation NASA space missions. PTFF is inflated by trapped photons between spacecraft mirrors, and stabilized by tethers, thus it is contamination-free and highly power efficient, and provides ample mass savings. In addition, PTFF is predicted to be able to provide an unprecedented angular scanning accuracy of 0.1 micro-arcsec, and the retargeting slewing accuracy better than 1 micro-arcsec for a 1 km baseline formation. These quantum-leaping capabilities of PTFF are predicted to enable emerging revolutionary mission concepts, such as New World Imager Freeway Mission proposed by Prof. Cash, which searches for advanced civilization in exoplanets and Fourier Transform X-Ray Spectrometer proposed by Dr. Schnopper, in addition to redefining and simplifying the existing NASA mission concepts, such as SPECS and MAXIM. As the present concept is more publicized, many other exciting concepts are predicted to follow. One of such possible NASA missions would be the construction of ultralarge adaptive membrane space telescope with diameters up to several km for observing and monitoring space and earth-bound activities. The conclusion of our Phase I study is that the implementation of the proposed method in the foreseeable future is well within reach of the present technologies. Therefore, we are confident that the proposed PTFF needs thorough continued study that will establish a reliable technical path to the launch of an exciting new class of NASA space mission. During this NIAC Phase II, we plan to build and demonstrate a prototype PTFF engine, address the engineering issues of key problems, and continue its full development for adapting PTFF for a wide range of NASA space missions in the near future with the help of several expert consultants.

Extraction of Antiparticles Concentrated in Planetary Magnetic Fields
Jim Bickford, Draper Laboratory, Inc.

Small quantities of antimatter have enormous potential in a variety of space, medical, and sensing applications. However, such systems have not yet been realized due to the inherent limitations associated with current antimatter production and storage techniques. The present method of extracting sub-atomic collision debris from high energy particle accelerators is prohibitively expensive and generates only minimal quantities of antiprotons. In comparison, high energy cosmic rays bombard the upper atmosphere and material in the interstellar medium to copiously produce antiparticles naturally. We propose to extend our Phase I study to address the realistic feasibility of natural antiparticle 'mining' for space applications. As described in our Phase 1 report, a fraction of the naturally generated antiprotons are concentrated around planets with magnetic fields. These antiparticles can be captured and stored in a man-made mini-magnetosphere surrounding a spacecraft and used to fuel an extremely high energy propulsion system, potentially enabling very fast missions to deep space (one year to Jupiter, and similarly fast trips beyond the heliopause [100+ AU] and beyond). While the initial study showed that antiparticles are a naturally occurring space phenomena in quantities sufficient to be of interest, the primary focus of our proposed two year study will be to do a detailed quantitative assessment of the mass of particles that could be collected, create comprehensive models of harvest systems, and conduct laboratory experiments to demonstrate these systems. The primary outputs of the study will include resolving the question of whether the natural supply is sufficient to justify development of mining tools, and will create a set of requirements and specifications for the design of the collection and storage device. In addition, we will develop a roadmap laying out key technology advancements that will be required to enable this capability, as well as a timeline for achieving those advancements.

Scalable Flat-Panel Nanoparticle MEMS/NEMS Propulsion Technology for Space Exploration in the 21st Century
Brian Gilchrist, University of Michigan

We have proposed and studied in Phase I a completely new style of charged particle space propulsion technology that uses nanoparticles and micro- and nano-electromechanical systems (MEMS/NEMS) technology. MEMS technologies are already being explored as a possible approach to achieve scalability and system simplification. Our Phase 1 results, which include scaled particle extraction experiments and modeling, have shown that the potential benefits we suggested in proposing Phase 1 were actually conservative! Specifically, we were able to determine that we can use nanoparticle field emission (extraction and acceleration) exclusively to cover an even broader range of performance than first thought (e.g., specific impulse covering 100 to 10,000 seconds). We believe the advantages include (1) operations at high power levels at substantially lower system level specific mass (kg/kW); (2) higher efficiency; (3) an order of magnitude increase in thrust densities over present-day ion propulsion technologies; (4) substantially simpler propulsion sub-system integration requirements on a spacecraft using “flat-panel” nanoparticle thrusters; and (5) substantial improvement in lifetime over state-of-the-art ion propulsion technology. We have also learned that (a) an operational range can be defined where particles can be extracted from a liquid surface and accelerated while avoiding the formation of efficiency-degrading Taylor cones; (b) low vapor pressure liquids can be used under high electric field conditions; and (c) there is already important research on-going with microfluidic transport of nanoparticles we can take advantage of in Phase 2. Our refined vision after Phase 1 is that in 10- 20 years, modern electric propulsion systems will be heavily leveraging nanoparticle and MEMS/NEMS technologies to address everything from the movement of propellant using micropumps, integrated microsensors for performance improvement (e.g., health monitoring), and high levels of scalability and system robustness.

Lorentz-Actuated Orbits: Electrodynamic Propulsion Without a Tether
Mason Peck, Cornell University

The NIAC Phase II investigation proposed here evaluates the feasibility of using the Lorentz force as a revolutionary means of accelerating a spacecraft. This force acts on a charged particle moving in a magnetic field, as in the case of a satellite carrying a biased electrical charge and orbiting within a planetary or stellar magnetosphere. This propellantless propulsion technique may represent the last area of classical physics that has not yet been considered for spaceflight dynamics. A spacecraft mission whose architecture is based on the Lorentz-Actuated Orbit benefits from propellantless, non-Keplerian orbits: for example, • Orbit planes that precess synchronously with the planet’s rotation, but at lower altitudes than the classical geostationary solution • Earth and solar escape (elliptical to hyperbolic orbits) and planetary capture (hyperbolic to elliptical) • Swarms of spacecraft that hover in non-Keplerian orbits, such as a formation of radially positioned vehicles with constant angular velocity at different altitudes • Rendezvous along the velocity direction, with no need for orbit raising and lowering • Orbits whose lines of apsides rotate synchronously with the planet, its moon, or the sun, offering continuous lunar free-return trajectories and lunar resupply possibilities • Low-earth orbits that experience neither cumulative atmospheric drag nor J2 perturbations.

We propose to build upon our successful Phase I study, which mapped out the heretofore unexplored, coupled dynamics of familiar celestial mechanics and cyclotron-style motion of a charged particle in a magnetic field and discovered a number of new system architectures for space travel. That project identified areas of technology advancement required for this system to be feasible and compared this concept to existing methods of propulsion in terms of key metrics: mass, power, cost, time of flight, and risk. The Phase II effort will focus on the feasibility issues by evaluating these low-TRL technologies to a point where Lorentz-actuated orbits can be considered for a future NASA mission. Our goals are the following: • Develop and exercise the algorithms and modeling tools required to understand spacecraft capable of experiencing a Lorentz-Actuated Orbit, including NASCAP and other in-house developed software for evaluating the coupled behaviors of spaceborneplasma charging and orbit dynamics. • Identify the lowest-risk charge-storage subsystem (i.e. capacitor) from among the technologies identified in the Phase I effort and detail its performance in the space environment, with an emphasis on plasma interactions. • Demonstrate and characterize the self-capacitance for the case of a scaled test in a representative plasma environment. • Identify the lowest-risk charge-maintenance subsystem (i.e. charged-particle source and related components) from among the technologies identified in the Phase I effort and detail its performance in the space environment, with an emphasis on plasma interactions • Devise a promising, candidate mission architecture in an effort to identify and tie up loose ends that would otherwise represent unacceptable risk to a NASA application.

An Architecture of Modular Spacecraft with Integrated Structural Electrodynamic Propulsion (ISEP)
Nestor Voronka, Tethers Unlimited, Inc.

NASA's Vision for Space Exploration (VSE) relies on numerous systems of systems to support a return of robotic and human explorers to the Moon in preparation for human exploration of Mars. Establishing a sustainable and continuous manned presence on the Moon, Mars, and deep space will require a very large total mass of material to be either launched from Earth, or obtained from the moon or asteroids and delivered for use in structural, propulsion, and shielding applications. Moving this material in near-Earth and cislunar space using traditional rocket-based propulsion requires propellant masses that represent a large fraction of the total required launch mass, and thus cost, of the exploration architecture. The Phase I effort established the feasibility of an innovative multifunctional propulsion-and-structure system concept, called Integrated Structural Electrodynamic Propulsion (ISEP), which uses current-carrying booms deployed from a spacecraft to generate thrust with little propellant expenditure. ISEP utilizes methods conceptually similar to electrodynamic tethers with the added benefit of providing a capability for generating thrust in almost any direction as well as for providing torques for spacecraft attitude control. This modular integrated propulsion architecture will facilitate self assembly of large space systems, and enable propulsion and attitude control of an assembled system during and after such assembly. During the Phase II effort, we propose to further refine the ISEP technology, and design an ISEP system for a mission of interest to NASA's VSE. As part of a development and risk mitigation program, TUI will design, build and launch a nanosatellite experiment that will demonstrate both the ISEP concept as well as propellantless current closure using field emissive array cathodes. This simple flight experiment will demonstrate the feasibility of using the ISEP architecture to reduce costs and enhance capabilities of NASA's Exploration Systems, Space Operations and Science Mission directorates.

APPENDIX E

Inspiration and Outreach Contacts

2006:

Jul 6. Diana Jennings met with fellow members of the Advisory Committee to the Cape Cod Junior Technology Council. The Committee has as its charter to provide input to enhance math and science education activities in Southeastern Massachusetts.

Jul 21. Diana Jennings gave an invited seminar to 20 students and 2 staff members at NASA Goddard's NASA Academy. Sharon Garrison also attended. The seminar included a dinner with the students and informal discussions. USRA /NIAC brochures and NIAC pins were distributed.

Jul 24-27. Bob Cassanova presented a seminar and conducted a "Grand Visions" workshop for the International Space University (ISU) Summer Studies Program (SSP) to students in Strasbourg, France. The seminar was attended by about 100 students and faculty and 23 students participated in the workshop. The output from the workshop and informal discussions will be one of the sources of "visions" to be included in the next NIAC Phase I Call for Proposals. The website for ISU is: http://www.isunet.edu/. His travel expenses were paid by ISU.

Jul 31-Aug 4. Ron Turner participated in the NSF/NASA sponsored Solar Heliospheric and Interplanetary Environment workshop in Midway Utah. This workshop looks at the science and consequences of space weather. Ron presented two posters based on his work as Participating Scientist (PS) on the Mars Odyssey spacecraft, and he included information about NIAC with his posters. The Odyssey PS Grant funded the travel.

Aug 22. Bob Cassanova gave an invited seminar to faculty and students of the Mechnical and Aerospace Engineering School of N. C. State University.

Sep 12. Diana Jennings served on a panel on workforce and education at the NRO/AIAA Space Integration meeting in Chantilly, Virginia.

Nov 2-5. Diana Jennings was elected to the Governing Board of the American Society for Gravitational and Space Biology (ASGSB). Jennings attended the meeting which was held in Arlington, VA, participating in a panel on funding opportunities on Nov 3, and a poster describing the NIAC program on Nov 4th.

Nov 12. Tricia Powers, Archive Researcher on a BBC Television documentary about weather modification entitled "Superstorm", contacted NIAC to obtain an image of NIAC Headquarters to use in their program.

Dec 1. Ron Turner received the 2006 Annual ANSER Platt Award (best published paper) for his article "Space Weather Challenges Intrinsic to the Human Exploration of Space" published in the American Geophysical Union Monograph Solar Eruptions and Energetic Particles, 2006. The NIAC's Director, Dr. Robert Cassanova, announced his plans to retire. USRA is conducting a national search for the new Director of NIAC. The position description is now available on the USRA website at: http://www.usra.edu/about/opportunities.shtml. An ad appeared in the Dec 8th issue of Science Magazine and the January issue of Aerospace America.

Dec 12-13. Ron Turner was appointed to the NRC panel, "Evaluation of Radiation Shielding for Lunar Exploration." The Panel's first meeting was Dec 12-13 in Washington DC.

2007:

Jan 11-12. Ron Turner attended the Venus Exploration Analysis Group meeting in Arlington, VA.

Jan 26. Robert Cassanova and Diana Jennings met with USRA's new President, Dr. Fred Tarantino, to provide a status report for NIAC. Dr. Tarantino's biosketch is available at http://www.usra.edu/about/sr-mgmt.shtml.

Jan 29. Ron Turner gave a presentation on "Radiation Risk Management on Human Missions to the Moon and Mars" at NASA Headquarters on January 29. Attendees included personnel from SMD and ESMD. There were a large number of call-ins from NASA centers, including JSC, MSFC, Glenn, and JPL. This exchange among the different communities will facilitate the design of an appropriate space weather architecture to support lunar missions.

Feb 6-7. Ron Turner presented on a panel discussing Space Weather Impact on Commercial Space Transportation at the FAA Office of Commercial Space Transportation's 10th Annual Commercial Space Transportation Conference Virginia.

Feb 8. Ron Turner attended the NASA Advisory Council Meeting. NIAC Science Council member Lester Lyles is also a member of the NAC.

Feb 11-15. NIAC was well-represented at the STAIF 2007 meeting in Albuquerque, NM. Diana Jennings and Ron Turner co-chaired a session on Biotechnology and Medicine for Space Colonization. Jennings presented a paper, co-authored with Ron Turner and Bob Cassanova, describing life-sciences-related NIAC studies. Ron Turner co-chaired a session on Space Exploration and also presented a paper, coauthored with Diana Jennings and Bob Cassanova, on the work of recently-funded NIAC Fellows. NIAC Fellow Dava Newman presented an important educational keynote address; and NIAC projects presented included those by Dava Newman, Brian Gilchrist, George Maise, Steve Dubowsky, and Constantinos Mavroidis.

Feb 21-22. Ron Turner's participation on the NRC Radiation Shielding Committee continued with his attendance at the committee's second meeting, held in Houston.

Mar 23. NIAC began collaborating with the staff of the Museum of Science and Industry (MSI) in Chicago. MSI has an average attendance of 2 million visitors per year. The museum recently used NIAC Fellow, Dr. Brad Edwards' concept, The Space Elevator, in their very popular "Da Vinci" exhibition. Dr. Edwards was cited as a "Modern Leonardo". NIAC held a teleconference to discuss the collaborative efforts with MSI. In attendance were Bob Cassanova, Diana Jennings, Ron Turner, and Kathy Reilly from NIAC. MSI attendees were John Beckman, Project Director, Kathleen McCarthy, Curator, David Woody, Director of Design, Patrick Gallagher, Gallagher &

Associates, Phil Hettema, Hettema & Associates. MSI wishes to use many NIAC Fellows' concepts in their upcoming exhibit, Exploration Mars. It is planned to begin in 2011 and run from 20 - 50 years. Additionally, MSI wants to collaborate with NIAC on a second exhibit beginning in 2008, their Technology Gallery. The Technology Gallery will focus on current and future technologies and will be updated on a regular basis. Essential to the educational mission of the museum, MSI staff plan to continue this exhibit indefinitely.

Mar 30. Turner and Jennings attended USRA's Annual Symposium. The topic of "Hands-on Training for Tomorrow's Space Researchers" was offered at the Sheraton Columbia, Maryland.

Apr 30. Diana Jennings, Ron Turner and Kathy Reilly attended the "Exploration Mars Advisory Committee" meeting at the Museum of Science & Industry at the Chicago Club in Chicago, IL on Apr 30, 2007. Organized by Kurt Haunfelner, V.P. of Exhibits & Collections, the NIAC staff was involved in discussions and a model walk-through for the proposed exhibit, "Exploration Mars" to open in 2011. The exhibit will showcase the world of exploration in many environments - deep oceans, caves, the arctic poles, and space travel to Mars. Several NIAC fellows' concepts were discussed and may be used in the exhibit including Penny Boston, Dava Newman, Wendy Boss and Robert Hoyt. Attendees included NIAC Fellow Penny Boston and Seth Shostak of the SETI Institute.

May 10-11. Ron Turner participated in the third meeting of the NRC Radiation Shielding Committee meeting May 10-11 in Washington DC.

May 15-17. Ron Turner attended the NSF Workshop on Small Satellite Missions for Space Weather and Atmospheric Research in Arlington, VA.

May 29-30. Diana Jennings attended the "Marine and Environmental Sciences Summit" in Woods Hole Mass May 29-30. Present at the meeting were staff of the major Woods Hole science institutions, business people, venture capitalists, and legislative aides.

Jul 18. Ron Turner met with Derek Tournear, a new DARPA Program Manager. They discussed several NIAC projects as possible new programs within DARPA. Mr. Tournear expressed interest and Ron sent him a copy of the NIAC/DARPA study conducted last year.

Jun 19-21. Ron Turner participated in the fourth and final meeting of the NRC Radiation Shielding Committee in Washington DC.

Jul 19-21

Diana Jennings attended the Space Frontier Foundation's "NewSpace 2007" in Crystal City, VA. The meeting included presentations from commercial space notables (such as Alex Tai of Virgin Galactic), traditional space companies, and NASA. Jennings distributed NIAC brochures and copies of the NIAC Return on Investment report. Attendees universally expressed disappointment at the closing of NIAC. Jennings also spoke with individuals such as Rosanna Satler of Boston, MA, an angel investor, about the work of Massachusetts-area NIAC Fellows.

Jun 27-29. Ron Turner attended the NASA Advisory Council (NAC) Biomedical Committee's workshop on opportunities and needs for biomedical research on the proposed lunar sorties and subsequent lunar outpost during the Lunar Biomedical Research Workshop.

Aug 2 & 30. Ron Turner attended meetings of the Radiation Task Group/Future Missions, near NASA HQ. This working group is led by the NASA Office of the Chief Engineer to coordinate Radiation-related activities throughout NASA

Aug 20. Bob Cassanova met with Bob Scaringe of AVG Communications to discuss funding opportunities for several NIAC Fellows to continue the development of their NIAC advanced concepts.

Aug 20. Kathy Reilly spoke with Kurt Haunfelner, Director of Exhibits at the Chicago Museum of Science and Industry and was invited to attend the October Committee Meeting of the Exploration Mars and Future Technologies exhibits.

Aug 22. The NIAC staff assembled in Atlanta to review final actions and celebrated the NIAC legacy with a concluding dinner.

Aug 28. Bob Cassanova met with Bill Gardiner from the National Space Society to discuss opportunities for documenting and continuing the legacy of NIAC.

Aug 27. Diana Jennings had a telephone meeting with members of the Governing Board of the American Society for Gravitational and Space Biology.

Aug 30. Bob Cassanova gave an invited dinner address to the Atlanta chapter of the AIAA.

APPENDIX F

NIAC Publicity

2006:

Jul 5. The July 2006 issue of Popular Science contains a short article about the NIAC-funded positron propulsion system being developed by Gerald Smith at Positronics Research LLC. Additional coverage appeared online:
NASA Website: http://www.nasa.gov/mission_pages/exploration/mmb/antimatter_spaceship.html
National Geographic website:
http://news.nationalgeographic.com/news/bigphotos/61447961.html
Also, the New York Times Syndicate requested the Positron Rocket image for a syndication article.

Jul 5. Webster Cash's Phase II project, The New Worlds Imager, is featured on the CNN website. The article describes the concept which has appeared in the international science journal, Nature. http://www.cnn.com/2006/TECH/space/07/05/space.shield.reut/index.html

Jul 6. The Italian weekly L'Espresso has an article titled "Alimentary Particles". The first page or so talks about the NIAC-sponsored project to create a Food Replicator. The article includes a picture of the printer created by Hod Lipson (with proper credit) and also mentions Homaro Cantu. The web site of L'Espresso is at http://espresso.repubblica.it, although a subscription is needed to find the article.

Jul 6. Bill Steigerwald of GSFC Public Affairs Office prepared a NASA HQ Press Release about the new NIAC Phase I and II Awards.

Jul 6. Webster Cash's NIAC-funded concept, The New Worlds Imager (also called the Starshade), is featured on the cover of the July 6, 2006 issue of NATURE and described in an article in this issue located at http://www.nature.com/news/2006/060703/full/060703-11.htm
This concept was also featured on PhysOrg.com: http://www.physorg.com/news71329220.html and PhysicsWeb UK: http://physicsweb.org/articles/news/10/7/1/1

Jul 6. World wide web references to announcement of 06-01 and 06-02 awards included:
Spaceref.com: http://www.spaceref.com/news/viewpr.html?pid=20279
PRNewswire: http://www.prnewswire.com/cgibin/stories.pl?ACCT=104&STORY=/www/story/07-06-2006/0004392746&EDATE=

Jul 13. Roger Angel's CP 06-01 Solar Shade concept resulted in web articles: International Reporter, India: (link no longer active) and the Tucson weekly http://www.tucsonweekly.com/gbase/Currents/Content?oid=oid:84372

Jul 17. John Slough's Plasma shield received coverage at NewScientist.com: http://space.newscientist.com/article/dn9567-plasma-bubble-could-protect-astronauts-on-mars-trip.html

Steven Dubowsky's cave-exploring hopper-bots were featured at numerous outlets:
Jul 18. Azom.com, http://www.azom.com/details.asp?newsID=6047,on MSNBC http://cosmi-

clog.msnbc.msn.com/archive/2006/07/18/1297.aspx, and at scenta.com (link no longer available).

Jul 25. National Geographic online: http://news.nationalgeographic.com/news/2006/07/060724-mars-robots.html

Jul 26. Cosmos magazine: http://www.cosmosmagazine.com/node/468

Jul 26. New Scientist Space
http://space.newscientist.com/article/dn9610-spherical-microrobots-could-explore-mars.html

Jul 19. Young K. Bae's NIAC -sponsored project is briefly described. Photonics.com.
http://www.photonics.com/content/spectra/2006/July/business/83285.aspx

Aug 8. Spaceref.com mentions NIAC and Brad Edwards in an article about the Space Elevator Games. http://www.spaceref.com/news/viewpr.html?pid=20558

Aug 25. Air and Space Magazine quotes NIAC Fellow Young K. Bae in an article about small satellites. http://www.airspacemag.com/issues/2006/august-september/NEED-smallsats.php

Sept 13-15. The work of NIAC Fellow Young Bae continued to receive press attention Azom.com
http://www.azom.com/details.asp?newsID=6682
Laser Focus International:
http://lfw.pennnet.com/Articles/Article_Display.cfm?ARTICLE_ID=271841&p=12

Sept 15. The NIAC-funded Biosuit, developed by Dava Newman at MIT, was described in a CNN TV broadcast.

Sept 15. A comment from Bob Cassanova was included in an article on the Space Elevator available on CNN at http://edition.cnn.com/2006/TECH/space/09/18/space.elevator/. NIAC Fellow Bradley Edwards is also quoted.

Sept 29. Lori Stiles of the University of Arizona provided a press release for the upcoming NIAC Annual Meeting. http://uanews.org/cgibin/WebObjects/UANews.woa/5/wa/SRStory Details?ArticleID=13165

Oct 10. Gentry Lee, one of NIAC's first Science Council members and a continuing supporter of NIAC was named to receive the Masursky Award.

Oct 12. Jeanne Allen, an author of science fiction and fantasy stories contacted NIAC. She is writing two chapters for a publication called "The Complete Guide to Writing Science Fiction," to be published by Dragon Moon Press. During her research, she saw the motto of NIAC and thought it would make an excellent heading for the chapter and requested use of it. Specifically, the line would be cited at the chapter's heading in the following manner: ["Don't let your preoccupation with reality stifle your imagination." Motto of NASA Institute for Advanced Concepts].

Oct 19. California section of the Los Angeles Times and the LATimes.org published an article entitled "Space Elevator Visions Going Up" describing a competition sponsored by NASA to inspire teams to develop concepts for lifting the most weight to the top of a 200 foot tether in the shortest time. The lifting concepts could be the forerunners of space elevator climbers. Link to the article is: http://www.latimes.com/technology/la-sci-xprize19oct19,1,6410013.story

Oct 19. The Arizona Daily Star published an article by Dan Sorenson entitled, "Future Space-gear Ideas Presented at NASA Meeting" that discusses the NIAC Annual Meeting held Oct 17-18, 2006 in Tucson, AZ. The full article is at: http://www.azstarnet.com/sn/relatedstories/151847.php

Oct 23. The work of NIAC Student Fellow Daniella Della-Guistina, which focuses on the possibility that asteroids could provide radiation protection for spacecraft was described on NewScientist.com at http://space.newscientist.com/channel/space-tech/dn10358-hitch-hike-to-mars-inside-an-asteroid.html

Oct 23. NIAC Fellow Brad Edwards provides an overview of the recent Space Elevator games. http://www.spaceref.com/news/viewnews.html?id=1166

Oct 29. Online publication "The Future of Things" features an interview with Dr. Gerald Smith, discussing his work with positron-based propulsion. http://www.tfot.info/content/view/88/64/

Oct 31. Roger Angel's Phase I concept for a sunshade was described in an on-line article in Sciencenow (a feature of the Journal Science), with a quote from Freeman Dyson. http://sciencenow.sciencemag.org/cgi/content/full/2006/1031/3

NIAC Student Fellow Rigel Woida enjoyed some publicity during the month of November, thanks to the hard work of Lori Stiles at the University of Arizona. Rigel's prize-winning work examines the possibility of using mirrors situated in space in order to create warm areas suitable for habitation on the Martian surface:

Nov 14. NewScientist.com. http://space.newscientist.com/article/dn10573-space-mir-rorscould-create-earthlike-haven-on-mars.html

Nov 16. Engadget, Canada
http://www.engadget.com/2006/11/16/asu-student-envisions-giant-space-mirrors-forterraforming-mars/

Nov 16. Zdnet. Another blog discussion inspired by the New Scientist article. http://blogs.zdnet.com/emergingtech/index.php?p=409

The work of NIAC Fellow Roger Angel utilizing millions of tiny sunshades to mitigate global warming was featured in online press this month, again thanks to a University of Arizona press release.

Nov 3. Physorg.com. http://www.physorg.com/news81795874.html

Nov 4. Yubanet. http://www.yubanet.com/artman/publish/article_45094.shtml

Nov 6. Digital Silence. http://www.d-silence.com/headlines/Space%20Sunshade/23340

Nov 6. MRT Online (Macedonia)
http://www.mrt.com.mk/en/index.php?option=com_content&task=view&id=1447&Itemid=33

The Dec Issue of AIAA Aerospace America was the annual "2006 -The Year in Review" and included a report by the AIAA Space Tethers Technical Committee. This report included a description of space tether experiments, the Multi-Application Survivable Tether (MAST) Experiment, being conducted by Tethers Unlimited Inc. (TUI). TUI was funded by NIAC in 1998 to develop a rotating momentum exchange space transportation concept which has received follow-on funding from NASA and DARPA. The report also included short descriptions of other related tethers concepts including, Momentum Transfer-Electrodynamic Reboost (MXER) Tether project and the NASA sponsored Centennial Challenges competition for tether strength improvement. This expansion of space tether development was inspired by the NIAC sponsored Phase I and Phase II contracts with TUI.

Dec 4. Bill Steigerwald, GSFC Public Affairs, prepared a NASA Press Release to announce the 2007 NIAC Phase I Proposal Call. The press release was held by ESMD until they complete their reevaluation of their FY07 program as a consequence of Congress' possible issuance of a continuing resolution for the remainder of FY07.

Dec 4. Space News' print version featured an article on Webster Cash's NIAC-funded concept, the New Worlds Observer. The article, entitled "Northrup-Grumman Concept uses Shades to Find New Planets" is also available online at http://www.space.com/spacenews/businessmonday_061204.html. NIAC was specifically mentioned. Also in the Dec 4th edition of Space News, other NIAC-funded projects, the lunar Liquid Mirror Telescope, and Electromagnetic Formation Flying, were mentioned in two other articles. These were available in the print version and online, for subscribers.

Dec 11. NIAC Fellow Young Bae was interviewed on The Space Talk Show. The interview can be accessed at http://www.thespaceshow.com. In the interview, NIAC was mentioned several times.

2007

Jan 13. NOVA broadcasted a 12-minute segment on the space elevator. NIAC Fellow Bradley Edwards was featured. The broadcast was also available on the web at http://www.pbs.org/wgbh/nova/sciencenow/3401/02.html>http://www.pbs.org/wgbh/nova/sciencenow/3401/02.html

Jan 16. The recent announcement of the NIAC Student Fellows Prize was published at SpaceRef.com at: http://www.spaceref.com/news/viewsr.html?pid=23063

Jan 22. The Futures Channel web site featured four videos on NIAC studies at their Living & Working in Space link. Featured material includes the Entomopter, a NIAC Overview, the BioSuit and the just released Space Sling. The Space Sling was filmed at the NIAC Annual Meeting in Oct 2006. http://www.thefutureschannel.com/living_working_space.php.

Jan 28, 29. The Discovery Channel hosted a program called "2057: The World" that discussed many new concepts for the future including a space elevator. The show is available at the following link:

http://dsc.discovery.com/tvlistings/episode.jsp?episode=3&cpi=25515&gid=14364&channel=DSC

Jan 29. TechLINKS Exchange (The Guide to Technology in Georgia) released an article about a firm that has provided marketing services to two NIAC clients, Fellows Young Bae and Mason Peck.
http://www.techlinks.net/CommunityAnnouncements/tabid/55/articleType/ArticleView/articleId/177472/A tlanta-Marketing-Team-Lands-New-Space-Research-Clients.aspx

Jan 30. CNN.com's Science and Space column features NIAC Science Council member, Jack Stuster, and his study of astronauts via their mission journals. The story is available at http://www.cnn.com/2007/TECH/space/01/30/astronaut.diaries.ap/index.html

Feb 5. USAToday.com. Article on Webster Cash New Worlds Imager at USAToday.com, http://www.usatoday.com/tech/science/columnist/vergano/2007-02-04-starshade_x.htm

Feb 7. Space.com. Article on the Kepler Mission cites Webster Cash's New Worlds Observer and NIAC. http://www.space.com/businesstechnology/070207_kepler_mission.html

Feb 14. NewScientist.com Featured Matthew Silver and His Bio-Electric Space Exploration Study. http://space.newscientist.com/article/dn11158-motionsensitive-spacesuits-could-generate-power.html. The article was also picked up on Nasawatch.com and discussed at Slashdot.com.

Feb 21. A PR Newswire Press released resulted in multiple instances of publicity for Dr. Young Bae's Phase II concept.
Photonics.com
http://www.photonics.com/content/news/2007/February/22/86585.aspx
Earthtimes.org
http://www.earthtimes.org/articles/show/news_press_release,64198.shtml
Yahoo! News http://biz.yahoo.com/prnews/070221/clw179.html?.v=6

Feb 22. A PR Newswire Press release resulted in multiple instances of publicity for Dr. Mason Peck's Phase I concept including:
SYS-CON Media, NJ http://www.sys-con.com/read/340844.htm
Space Daily
http://www.spacedaily.com/reports/Cornell_To_Study_Planetary_Magnetic_Fields_Propulsion_Research_Under_NASA_Grant_999.html

Feb 24. Outlook Series Interview with NIAC Director, Bob Cassanova Bob Cassanova was interviewed by Mike Lippis for a segment in the Outlook Series that is currently being broadcast over radio and the internet. The interview covers a general description of NIAC and gives special emphasis to Roger Angel's NIAC-developed advanced concept, the "Sunshade". The interview is available at the link: http://www.outlookseries.com/RADIO/NIAC_Space_Sunshade.htm

Feb 26. NIAC Fellow Webster Cash presented his New Worlds Imager concept at GSFC's Engineering Colloquium.

Mar 14. Mason Peck's new Phase 1 received media attention on Slashdot and on the Malaysia Sun website:
http://science.slashdot.org/article.pl?sid=07/03/13/2051208

http://story.malaysiasun.com/index.php/ct/9/cid/89d96798a39564bd/id/234148/cs/1/

Much publicity focused on the termination of the NIAC contract. Not shown below is the large number of blogs that picked up the news and discussed it.

Mar 21. Nasawatch.com http://www.nasawatch.com/archives/2007/03/
New Scientist. http://space.newscientist.com/article/dn11422-futuristic-nasa-think-tank-to-be-shut-down.html

Mar 21. Slashdot: http://science.slashdot.org/article.pl?sid=07/03/21/1259208

Mar 21. The Hindu, India. http://www.hindu.com/thehindu/holnus/008200703220340.htm

Mar 22. Daily Tech, IL http://www.dailytech.com/NASA+to+Shut+Down+Think+Tank/article6591c.htm

Mar 22. Hartford Courant, CT http://www.courant.com/features/lifestyle/hc-closing.art-mar22,0,153336.story?coll=hcheadlines-life

Mar 23. Houston Chronicle, TX.
http://www.chron.com/disp/story.mpl/space/4657530.html

Mar 25. Taipei Times, Taiwan
http://www.taipeitimes.com/News/editorials/archives/2007/03/26/2003353951

Mar 28. Atlanta Journal and Constitution, GA
http://www.ajc.com/metro/content/metro/stories/2007/03/28/0329meshnasa.html

Apr 8. NIAC Science Council member John Cramer describes the controversial quantum theory prediction he would like to test:
http://seattlepi.nwsource.com/local/310821_quantum09.html

Apr 19. Devon Crowe's Phase I work was featured in two websites:
http://www.centauri-dreams.org/?p=1169
http://advancednano.blogspot.com/2007/04/possibly-last-niac-studies-are-being.html
Webster Cash's New Worlds Observer work is also mentioned in the Centauri Dreams entry, with a link to his new website at http://newworlds.colorado.edu/

Apr 23. Roger Angel was featured in *Astrobiology Magazine*. If global warming sizzles out of control, could 16 trillion small disks deflect enough sunlight to cool the planet? Astronomer Roger Angel proposes to find out.
http://www.astrobio.net/news/modules.php?op=modload&name=News&file=article&sid=2309&mode=thread&order=0&thold=0

May 1. The May issue of *Ad Astra* includes an opinion piece written by NIAC PI Matthew Silver on the subject of why NASA needs NIAC. It has been published in printed form but the pdf was made available at the NIAC web site.
http://www.niac.usra.edu/files/misc/Ad_Astra_Op_Ed_msilver.pdf

May 4. Jeff Hoffman, a NIAC Fellow, MIT Professor, and Astronaut, was inducted into the Astronaut Hall of Fame in May 2007. More details are at the following Aero-News.Net article link. http://www.aero-news.net/index.cfm?ContentBlockID=7805e910-2ea6-4da6-898a-bfb924c23951

May 13. Clarkson University News. Senior Andrew T. Bingham of Enosburg Falls, past NIAC Student Fellow, was featured. Andrew has graduated and will take a full-time position at JPL.

May 14, 15. Matthew Silver's Phase I concept was profiled on two sites:
Astrobiology Magazine:
http://www.astrobio.net/news/modules.php?op=modload&name=News&file=article&sid=2331&mode=thread&order=0&thold=0
Space Daily:
http://www.spacedaily.com/reports/Power_In_Space_Time_For_A_Biological_Solution_999.html

May 20. Roger Angel's Phase II project, building a lunar liquid mirror telescope, was featured on two sites:
Wired.com: http://www.wired.com/science/space/news/2007/05/liquid_telescope
Engadget.com: http://www.engadget.com/2007/05/29/mammoth-liquid-mirrortelescope-could-be-constructed-on-the-moon/

Jun 6. Fox News. Penny Boston's work on the Caves of Mars Project, initially funded by NASA, is mentioned in an article concerning discovery by the Mars Reconnaisance Orbiter of a deep hole on Mars.
http://www.foxnews.com/story/0,2933,278698,00.html

Jun 21. Roger Angel's NIAC funded advanced concept is described at the following link for the June 21, 2007 Nature article entitled: "Deposition of metal films on an ionic liquid as a basis for a lunar telescope." Roger and Pete Worden are two of the authors of the article.
http://www.nature.com/nature/journal/v447/n7147/abs/nature05909.html

Jun 20, 21. Several instances of publicity, including international outlets, covering the Nature Article on the Lunar Liquid Mirror Telescope:
Centauri Dreams: http://www.centauri-dreams.org/?p=1323
Channel 4 News, UK: http://www.channel4.com/news/articles/science_technology/giant+telescope+bound+for+moon/568077
CNetNews.com: http://news.com.com/8301-10784_3-9732872-7.html
CBC Ottawa: http://www.cbc.ca/technology/story/2007/06/20/liquid-mirror.html
Malaysia Sun:
http://story.malaysiasun.com/index.php/ct/9/cid/89d96798a39564bd/id/258371/cs/1/
Science Daily: http://www.sciencedaily.com/releases/2007/06/070620154940.htm

Jun 29. Bob Cassanova was interviewed by Dr. W. Patrick McCray,
Associate Professor, Department of History, University of California, Santa Barbara. Dr. McCray is a historian of science at UCSB and is working on a project about pro-technology advocacy groups. He plans to write a paper that will be presented at the annual meeting of the Society for History of Technology in Washington, DC on October 17-21, 2007. He is considering using a few

of the NIAC advanced concepts in his paper, such as the Space Elevator and the Rotating Momentum Exchange Tether.

Jul 7. NIAC Closing discussed
http://www.spacepolitics.com/2007/07/07/griffin-on-funding-advanced-technology-work/

Jul 9. Bob Cassanova corresponded with research editor Terri Rooks of US Airways Magazine, the monthly inflight publication for US Airways. The magazine will include an article written by Kristin Ohlson, in its September issue about Space Elevators. Bob and NIAC are referenced in the article.

Jul 11. Liquid Mirror Telescope discussed.
http://crave.cnet.com/8301-1_105-9732872-1.html

Jul 12. Bob Cassanova corresponded with Molly Webster of NPR Science Friday regarding Dava Newman's Biosuit.

Throughout July there was extensive discussion of Dava New's Biosuit in blogs (too numerous to compile) and media outlets. At least 38 websites featured Dava's work, including the following:

Jul 16. Wired News. http://blog.wired.com/wiredscience/2007/07/spacesuits-just.html

Jul 17. USAToday.com http://www.usatoday.com/tech/science/space/2007-07-17-slim-future-spacesuits_N.htm

Jul 17. National Geographic. http://news.nationalgeographic.com/news/2007/07/photogalleries/spacesuit-pictures/

Jul 18. Foxnews.com. http://www.foxnews.com/story/0,2933,289661,00.html

Jul 23. Time.com http://www.time.com/time/health/article/0,8599,1646046,00.html

Aug 1. Dava Newman's Biosuit continued to receive media attention.
http://www.digitaljournal.com/article/212287/One_Step_for_Space_Fashion_One_Giant_Leap_for_Astronaut_Safety

Aug 15. Mason Peck's work in magnetic propulsion was featured on the Popular Science Website.
http://www.popsci.com/popsci/aviationspace/8afbd66d69c34110vgnvcm1000004eecbccdrcrd.html

Aug 16. Diana Jennings had a long telephone conversation about the Space Elevator with reporter Lee Gomes of the Wall Street Journal.
http://online.wsj.com/article/SB118773478835004552.html?mod=googlenews_wsj

APPENDIX G

2006 - 2007 NIAC Fellows Publication Listing

Angel, Roger:

Angel, R., Eisenstein, D., Sivanandam, S., Worden, S., Burge, J., Borra, E., Gosselin, C., Seddiki, O., Hickson, P., Ma, K., Foing, B., Josset, J-L, Thibault, S., “A Deep Field Infrared Observatory Near the Lunar Pole”, International Lunar Conference, 2005.

Roger Angel, Dan Eisenstein, Suresh Sivanandam, Simon P. Worden, Jim Burge, Ermanno Borra, Clement Gosselin, Omar Seddiki, Paul Hickson, Ki Buri Ma, Bernard Foing, Jean-Luc Josset, Simon Thibault, Paul van Susante, “A Lunar Liquid Mirror Telescope (LLMT) For Deep-Field Infrared Observations Near the Lunar Pole”, SPIE Proc. Space Telescopes and Instrumentation I: Optical, Infrared, and Millimeter, eds. J. C. Mather, H. W. MacEwen, M. W. de Graauw, 6265, Orlando, 2006.

Bickford, James:

J. Bickford, W. Schmitt, W. Spjeldvik, A. Gusev, G. Pugacheva, I. Martin, "Natural Sources of Antiparticles in the Solar System and the Feasibility of Extraction for High Delta-V Space Propulsion", New Trends in Astrodynamics Conference, Princeton, NJ, 16-18 August, 2006.

G. Pugacheva, A. Gusev , V. Pankov , J. Bickford , W. Spjeldvik , U. Jayanthi , and I. Martin, "Antiparticle content in planetary magnetospheres and its possible use as fuel for remote heliosphere space missions", COSPAR 2006, Beijing, China, 16-23 July 2006.

Boss, Wendy:

Im, Y.J., M. Ji, A.M. Lee, W. F. Boss, A.M. Grunden. 2005. Production of a thermostable archaeal superoxide reductase in plant cells. FEBS Letters. 579:5521-5526.

The results were presented at the following meetings:
Ji ML, Im YJ, Lee AM, Boss WF, Grunden, AM. 2005. Recombinant expression of superoxide reductase from the hyperthermophilic archaeon Pyrococcus furiosus in tobacco cell culture. 105th General Meeting of the American Society for Microbiology, Atlanta, GA

Ji ML, Im YJ, Lee AM, Boss WF, Grunden AM. 2005. Recombinant expression of superoxide reductase from the hyperthermophilic archaeon Pyrococcus furiosus in Tobacco cell culture. North Carolina Chapter of the American Society for Microbiology, Raleigh, NC.

Cash, Webster:

Webster Cash, Jeremy Kasdin, Sara Seager, Jonathon Arenberg "Direct studies of exoplanets with the New Worlds Observer", Proc. Soc. Photo-Opt. Instr. Eng., 5899, 0S1-0S12, 2005.

Schindhelm, E., Cash, W., Seager, S., "Science simulations for the New Worlds Observer", Proc. Soc. Photo-Opt. Instr. Eng., 5905, 455-463, 2005

Cash, W., "Direct observation of exoplanets with a flower-shaped occulter", NATURE, submitted, 2006.

Komerath, Narayanan:

Wanis, S.S., Komerath, N.M., "Validation of TFF Concept for Use in Space Based Construction" STAIF 2006-081, Proceedings of the Space Technology Applications International Forum, Albuquerque, NM, February 2006.

Wanis, S.S., Komerath, N.M., "Designs for Space-Based Construction Using Force Fields" ASCE Earth and Space 206 conference, League City, TX, March 2006.

Rangedera, T., Vanmali, R., Shah, N., Zaidi, W., Komerath,N., "A Solar-Powered Near Earth Object Resource Extractor". Proceedings of the first Georgia Tech Space Space Systems Engineering Conference, Atlanta, November 2005.

Vanmali, R., Li, B., Tomlinson, B., Zaidi, W., Komerath, N., "Conceptual Design of a Multipurpose Robotic Craft for Space Based Construction". AIAA2005-6733, Space 2005, Long Beach, CA August 30-Sep. 2, 2005.

Vanmali, R., Tomlinson, B., Li, B., Wanis, S., Komerath, N., "Engineering a Space Based Construction Robot," 05WAC-44 SAE World Aerospace Congress, 2005.

Wanis, S., Komerath, N., "Advances in Force Field Tailoring for Construction in Space". Paper IAC2005_D1.1.02, International Astronautical Federation Conference in Fukuoka, Japan, Oct. 15-21, 2005 .

Abstract: B. Tomlinson, B. Li, S.Wanis, N. Komerath, Engineering a Space Based Construction Robot, SAE, World Aerospace Conference, August 2005.

Abstract: B. Tomlinson , B. Li, R. Vanmali, S.Wanis , N. Komerath, Conceptual design of a Multipurpose Robotic Craft for Space Based Construction. AIAA Space 2005 Conference, September 2005.

Abstract: Wanis, S., Komerath, N.M., "Advances in Force Field Tailoring for Construction in Space", IAF, Congress, Fukuoka, Japan, October 2005.

Peck, Mason:

M. Peck, "Prospects and Challenges for Lorentz-Augmented Orbits," Journal of Guidance, Control, and Dynamics (submitted).

Todd, Paul:

P. J. Boston, P. Todd and K. R. McMillen. Robotic Lunar Ecopoiesis Test Bed: Bringing the Experimental Method to Terraforming. Space Technology and Applications International Forum - STAIF 2004, Ed. M. S. El-Genk, American Institute of Physics, Washington, DC, 2004.

D. J. Thomas, S. L. Sullivan, A. L. Price, and S. M. Zimmerman. Common freshwater cyanobacteria grow in 100% CO_2. Astrobiology 5(1) 66-74, 2005.

D. J. Thomas and S. K. Herbert. An Inexpensive Apparatus for Growing Photosynthetic Microorganisms in Exotic Atmospheres. Astrobiology (1), 75-82, 2005.

P. Todd. Planetary biology and terraforming. Gravitational and Space Biology 19 (2), submitted 2005.

P. J. Boston, P. Todd, D. J. Thomas and K. Mcmillen. Toward a concept of habitability: Applications to experimental ecopoiesis. Gravitational and Space Biology 19 (2), submitted 2005.

D. J. Thomas, J. Boling, P. J. Boston, K. A. Campbell, T. McSpadden, L. McWilliams and P. Todd. Extremophiles for ecopoiesis: Desirable traits for and survivability of pioneer Martian organisms. Gravitational and Space Biology 19 (2), submitted 2005.

D. J. Thomas, P. Todd, P. J. Boston, J. Boling, T. McSpadden and L. McWilliams. Early results of ecopiesis experiments in the SHOT Martian environment simulator. Proceedings of the Eighth International Mars Society Convention, submitted 2005.

P. Todd, P. J. Boston, H. Platt and G. W. Metz. Environmental simulators for experimental ecopoiesis. Gravitational and Space Biology 18(1) Abstract #81, p. 33, 2004.

N. A. Thomas, P. Todd, G. W. Metz, H. Platt, and D. J. Thomas. Performance evaluation of a laboratory test bed for planetary biology. 21st Meeting of the American Society for Gravitational and Space Biology, Reno, NV, Gravitational and Space Biology 19 (1), Abstract # 77, p. 33,1-4 Nov 2005.

P. Todd. Planetary biology and terraforming. 21st Meeting of the American Society for Gravitational and Space Biology, Reno, NV, Gravitational and Space Biology 19 (1), Abstract # 95, p. 46, 1-4 Nov 2005.

P. J. Boston, P. Todd, D. J. Thomas and K. Mcmillen. Toward a concept of habitability: Applications to experimental ecopoiesis. 21st Meeting of the American Society for Gravitational and Space Biology, Reno, NV, Gravitational and Space Biology 19 (1), Abstract #97, p. 46, 1-4 Nov 2005.

D. J. Thomas, J. Boling, P. J. Boston, K. A. Campbell, T. McSpadden, L. McWilliams and P. Todd. Extremophiles for ecopoiesis: Desirable traits for and survivability of pioneer Martian organisms. 21st Meeting of the American Society for Gravitational and Space Biology, Reno, NV, Gravitational and Space Biology 19 (1), Abstract #98, p. 46, 1-4 Nov 2005.

An "expanded abstract" was published in Gravitational and Space Biology 14 (2) 2005, with the following content: Environmental Simulators for Experimental Ecopoiesis, P. Todd, P. J. Boston, H. Platt, G. W. Metz. SHOT, Inc., Greenville, IN, Center for Cave and Karst Studies, New Mexico Institute of Mining and Technology, Socorro, NM.

Abstract- Eighth International Mars Society Convention, Boulder, CO, August 11-14, 2005. Early Results of Ecopoeisis Experiments in the SHOT Martian Environment Simulator. David J. Thomas, Paul W. Todd, Penelope J. Boston, John Boling, Tiffany McSpadden and Laura McWilliams.Lyon College, Science Division, Batesville, AR 72501, Space Hardware Optimization

Technology, Inc., Greenville, IN 47124, Complex Systems Research, Inc., Boulder, CO 80301.

Woolsey, Craig:

M. Morrow and C. Woolsey and G. Hagerman", "Exploring Titan with autonomous, buoyancy-driven gliders", "Journal of the British Interplanetary Society", 59" (1) pp.27-34, January, 2006.

MASTER'S THESIS: "M. Morrow"
"A Self-Sustaining, Boundary-Layer-Adapted System for Terrain Exploration and Environmental Sampling,Virginia Polytechnic Institute & State University, June, 2005.

"Creativity and imagination are necessities, not luxuries."

Robert A. Cassanova, NIAC Director

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