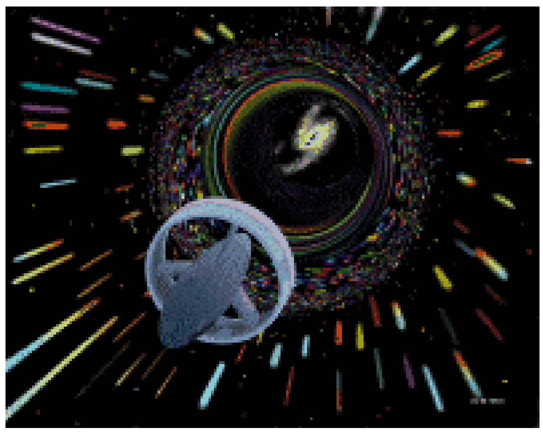
Welcome to the

NASA Breakthrough Propulsion Physics (BPP) Project

Public Information Site



To see more BPP artwork click on the picture

ABOUT BPP

NASA supported the Breakthrough Propulsion Physics Project from 1996-2002 to seek the ultimate breakthroughs in space transportation: (1) propulsion that requires no propellant mass, (2) propulsion that attains the maximum transit speeds physically possible, and (3) breakthrough methods of energy production to power such devices. Topics of interest include experiments and theories regarding the coupling of gravity and electromagnetism, the quantum vacuum, hyper fast travel, and super luminal quantum effects. Because the propulsion goals are presumably far from fruition, a special emphasis is to identify affordable, near-term, and credible research that could make measurable progress toward these propulsion goals.

This web site describes the methods and activities of the Breakthrough Propulsion Physics Project. For an introduction about the challenges of interstellar travel and some of the emerging concepts, please visit our "Warp

Drive- When?" site.

The Breakthrough Propulsion Physics Project is managed by Marc Millis of the Glenn Research Center (GRC), and was sponsored by the Advanced Space Transportation Program (ASTP), managed by NASA Marshall Space Flight Center, Huntsville, AL. In the Summer of 2002, both the Breakthrough Propulsion Physics Project and the Revolutionary Propulsion Research Project, that were part of ASTP's "Revolutionary Research Investment Area," were removed from the ASTP. It is not certain if or when funding for such research will resume.

CONTENTS

NEWS

- (June 3, 2004) Posted summary of BPP research (w/corrected references).
- (May 13, 2004) Minor revisions incorporated throughout.
- (January 31, 2003) Revisions incorporated to reflect the end of Project funding.
- (November 18, 2002) Aerospace Commission recommends funding basic research toward breakthroughs.

OVERVIEW OF BPP

- Summary of BPP Project research and related research (NASA-TM-2004-213082)
- Formal BPP Project Plan (Fiscal Year 2001) (What, Why, How, and Who).
- Description of project goals, methods, and emerging opportunities (10 pages including reference list).
- Common Errors - posting of erroneous breakthrough propulsion concepts commonly received.
- Special Challenges - description of why this work is more difficult than just the physics (includes links to sample submissions).
- Progress Notes - Short statements of noteworthy events.
- Archive
- Project Overview Presentation (About 30 [obsolete] slides, but no accompanying text).
- Previous call for proposals (As reference for future calls for proposals).

BPP JOURNAL PUBLICATIONS:

- Millis, M.G., "NASA Breakthrough Propulsion Physics Program", *Acta Astronautica*, **44** (1999), pp. 175-182.
- Millis, M.G., "Challenge to Create the Space Drive", *AIAA Journal of Propulsion and Power*, **13** (1997), pp. 577-582.
- Maclay, G. J., "Analysis of zero-point electromagnetic energy and Casimir forces in conducting rectangular cavities", *Physical Review A*, **61** (2000), pp. 052110-1 to 052110-18.
- Mojahedi, M., Schamiloglu, Hegeler, and Malloy, "Time-domain detection of superluminal group velocity for single microwave pulses", *Physical Review E*, **62** (2000) pp. 5758-5766. [First direct time-domain measurement of superluminal group velocities for microwave pulses through one-dimensional photonic crystals.]
- Mojahedi, M., Schamiloglu, Kamil,, and Malloy, "Frequency Domain Detection of Superluminal Group Velocities in a Distributed Bragg Reflector", *IEEE Journal of Quantum Electronics*, **36** (2000), pp. 418-424.
- Segev, B., Milonni, Babb, and Chiao, "Quantum noise and superluminal propagation", *Physical Review A*, **62** (2000), pp. 0022114-1 - 0022114-15.
- Villarreal, C., Esquivel-Sirvent, and Cocoletzi, "Modification of Casimir

Forces due to Band Gaps in Periodic Structures", *International Journal of Modern Physics A*, **17** (2002), pp. 798-803.
- Esquivel-Sirvent, R., Villarreal, and Cocoletzi, "Superlattice-mediated tuning of Casimir forces", *Physical Review A*, **64** (2001), pp. 052108-1 to 052108-4.
- Maclay, G.J., Fearn, and Milonni, "Of some theoretical significance: implications of Casimir effects", *European Journal of Physics*, **22** (2001), pp. 463-469.
- Esquivel-Sirvent, R., Villarreal, Mochan, and Cocoletzi, "Casimir Forces in Nanostructures", *Physica Status Solidi (b)*, **230** (2002), pp. 409-413.
- Mochan, W.L., Esquivel-Sirvent, and Villarreal, "On Casimir Forces in Media with Arbitrary Dielectric Properties", *Revista Mexicana de Fisica*, **48** (2002), p. 339.
- Milonni, P.W., and Maclay, "Quantized-Field Description of Light in Negative-Index Media," *Optics Communications*, **228** (2003), pp. 161-165.
- Maclay, J. and Forward, R., "A Gedanken spacecraft that operates using the quantum vacuum (adiabatic Casimir effect)", *Foundations of Physics*, **34** (March, 2004) pp. 477-500.

PROJECT PUBLICATIONS:

The following publications are from the NASA BPP Project. In those cases where electronic copies are available, links are indicated. To get paper copies of US Government reports, contact the National Technical Information Service (NTIS) (There is a modest per-page fee associated with copies.) To get copies of AIAA reports, contact the American Institute of Aeronautics and Astronautics (There is a fee associated with copies.)

- Millis (2004) "Prospects for Breakthrough Propulsion from Physics," NASA TM-2004-213082
- BPP-sponsored papers from July 2001 Joint Propulsion Conference. NOTE that only **5** of the papers listed (those with electronic copies posted) are those sponsored by the BPP Project. The list of 2001 Joint Propulsion Conference BPP Session papers, also includes papers sponsored by others. Posting on this list of these other papers does not in any way imply NASA endorsement of their contents
- Millis and Williamson, ed., (1999) "NASA Breakthrough Propulsion Physics Workshop Proceedings," NASA/CP-1999-208694, Proceedings of a

conference held at and sponsored by NASA Lewis Research Center in Cleveland Ohio, August 12-14, 1997. (Jan. 99) (456 pg.). NOTE: a short workshop summary, NASA TM-97-206241, is available electronically.

- Millis (1998) "NASA Breakthrough Propulsion Physics Program", NASA/TM-1998-208400
- Millis (1997) "Breakthrough Propulsion Physics Workshop Preliminary Results," NASA TM-97-206241
- Millis (1997) "Challenge to Create the Space Drive," *AIAA Journal of Propulsion and Power*, Vol. 13, pp. 577-582
- Millis (1996) "Breakthrough Propulsion Physics Research Program," NASA TM-107381

CONFERENCE PUBLICATIONS:

The following publications consist of conference or workshop sessions, listed in reverse chronological order, that contain papers submitted to the BPP Project. Inclusion of these papers does not in any way imply NASA endorsement of their contents.

- 37th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Salt Lake City, UT, 2001. (Click here for Paper List) El-Genk, M. S., ed. (2000) "Space Technology and Applications International Forum 2000," American Institute of Physics, AIP Conference Proceedings 504. (The papers on BPP topics are in pages 998-1132.)
- 35th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Los Angeles, CA, 1999. (The papers on BPP topics are AIAA 99-2143 through AIAA 99-2147
- El-Genk, M. S., ed. (1999) "Space Technology and Applications International Forum 1999," American Institute of Physics, AIP Conference Proceedings 458. (The papers on BPP topics are in pages 875-937 and 954-1059.)
- Millis and Williamson, ed., (1999) "NASA Breakthrough Propulsion Physics Workshop Proceedings," NASA/CP-1999-208694, Proceedings of a conference held at and sponsored by NASA Lewis Research Center in Cleveland Ohio, August 12-14, 1997. (Jan. 99) (456 pg.). NOTE: a short workshop summary, NASA TM-97-206241, is available electronically.

- 34th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Cleveland, OH, 1998. (The papers on BPP topics are AIAA 98-3136 through AIAA 98-3143)
- El-Genk, M. S., ed. (1998) "Space Technology and Applications International Forum 1998," American Institute of Physics, AIP Conference Proceedings 420. (The papers on BPP topics are in pages 1435-1461 and 1502-1534.)
- Li, N., Noever, D., Robertson, T., Koczor, R., and Brantley, W. (1997) "Static Test for a Gravitational Force Coupled to Type II YBCO Superconductors," In Physica C, Vol. 281, pp. 260-267.

RESEARCH SUMMARIES

- Millis (2004) "Prospects for Breakthrough Propulsion from Physics," NASA TM-2004-213082
- BPP-sponsored papers from July 2001 Joint Propulsion Conference. NOTE that only **5** of the papers listed (those with electronic copies posted) are those sponsored by the BPP Project. The list of 2001 Joint Propulsion Conference BPP Session papers, also includes papers sponsored by others. Posting on this list of these other papers does not in any way imply NASA endorsement of their contents
- Description of competitively awarded BPP research tasks
- Assessing the unsolved challenges of propulsion without propellant (from the AIAA Journal of Propulsion and Power)

WHAT'S NEXT

The BPP Project has been "deferred" since January 2003. It is unknown if or when funding will resume.

The research Consortium that was initiated in January 2002 with the Ohio Aerospace Institute (OAI) is still on hold. This was the next stage of the Breakthrough Propulsion Physics Project. The Consortium would manage future research solicitations with the help of an Advisory Council including renowned physicists, and would support a database of BPP research opportunities and findings.

Funding for the BPP documentation contractor (who handled the 1000+/yr unsolicited correspondences, bibliography, and research documentation) ran out in September 2003.

OTHER GOVERNMENT ACTIVITIES

Note: Some of these links will take you out of the NASA domain. Use your browser's "back" feature if you wish to return to this NASA site.

- NASA Home Page
- NASA Glenn Research Center at Lewis Field
  - Programs and Projects at Glenn
  - Pioneering Ion Propulsion Research
  - Space Propulsion Research
  - Microgravity Research
- NASA Space Transportation Programs (NASA MSFC)
- NASA Science News (NASA MSFC)
- NASA Office of Space Science (NASA HQ)
- NASA Origins Program
- Gravity Probe B
- LIGO- Laser Interferometer Gravitational-Wave Observatory
- Fundamental Physics in Microgravity Research Program
- Interstellar Probe Missions:
  - Missions under consideration by the NASA Office of Space Science
- NASA Institute for Advanced Concepts
- USAF European Office of Aerospace Research & Development (EOARD)

NON-GOVERNMENT LINKS

Note: These links are provided for the convenience of Internet users.

Links do not imply NASA endorsement of any group or organization outside the Agency. These links will take you out of the NASA domain. Use your browser's "back" feature if you wish to return to this NASA site.

- Quantum Fields - LLC
- Essays about cutting-edge science by John G. Cramer
- Chiao Group Home Page
- Tutorial on Particle Physics
- About the IBM Quantum Teleportation Research

PRESS COVERAGE:

- Mallon, Thomas, "Onward and Outward", in New York Times, Editorial / Op-Ed, (February 5, 2003)
- DiChristina, Mariette, "Space at WARP Speed", in Popular Science, p 47-51, (May 2001)
- Millis, Marc G., "The big mystery: Interstellar travel", MSNBC News, 4 pages, (Monday, November 2, 1998) (http://www.msnbc.com/news/207618.asp)
- Rogers, Adam, "Department of Warp Drive and Wormholes", in Newsweek, p.12, (August 31, 1998).
- Greenwald, Jeff, "To Infinity... and Beyond", in Wired, p 90-97, (July 1998).
- Burkey, Martin (Times Aerospace/Science Writer), "Science fiction blends with science as experts discuss NASA studies", in The Huntsville Times, p B4, (Thursday, February 12, 1998)
- Kuznik, Frank, "The Need for Speed", in Smithsonian Air & Space, p 15-16, (December 1997/January 1998)
- Millis, Marc G., "Breaking Through To The Stars", in Ad Astra, p 36-40, (January/February 1997)
- David, Leonard, "Warning: Mind Fields", in Final Frontier, p.19-23 (January/February 1997)

FREQUENTLY ASKED QUESTIONS

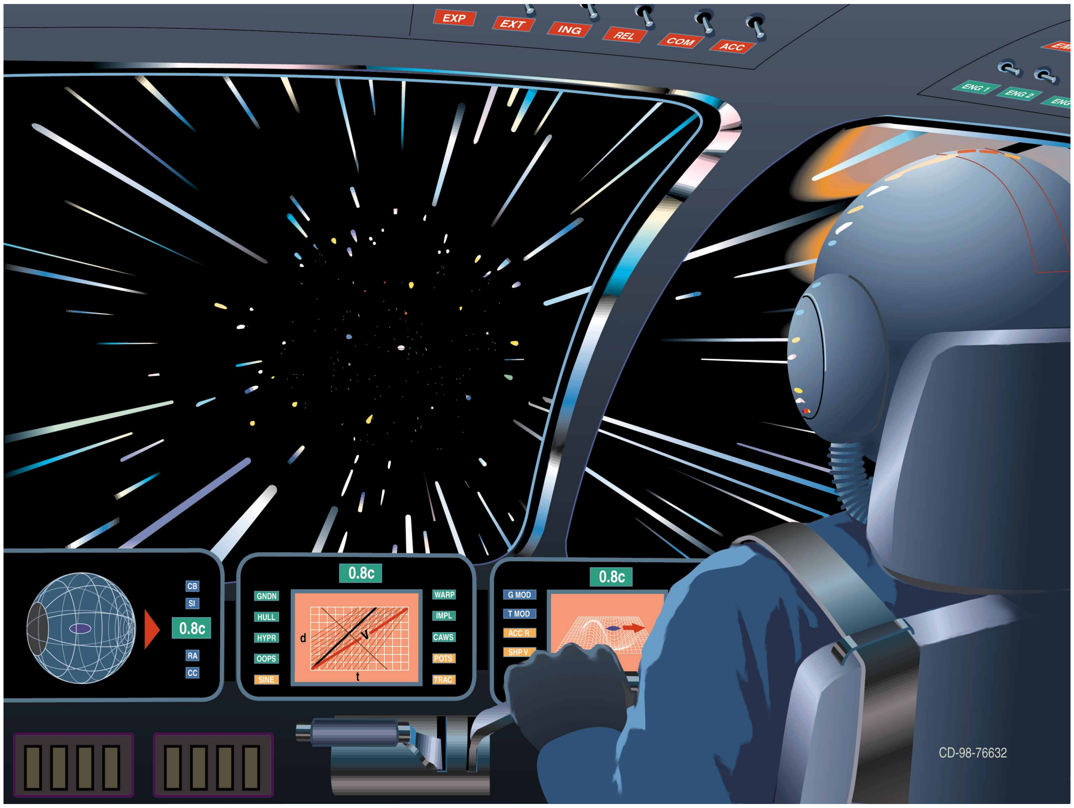
Responsible Official for Content: Marc G. Millis
Curator: -- not presently available --
Last update: June 3, 2004

Privacy Statement

NASA Breakthrough Propulsion Physics Project
Art

CD-98-76634

This rendition, by artist Les Bossinas, depicts a hypothetical spacecraft with a "negative energy" induction ring, inspired by recent theories describing how space could be warped with negative energy to produce hyperfast transport to reach distant star systems.



CD-98-76632

This rendition, by artist Les Bossinas, depicts a cockpit view of a hypothetical spacecraft traveling at eight-tenths the speed of light and shows the visual distortions that would be experienced at such high speeds. The star field is actually being wrapped toward the front of the craft in addition to being significantly blue-shifted.

Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004

Breakthrough Propulsion Physics Project

Marc Millis' Biography

Marc G. Millis
AST, Propulsion Physics.
NASA Glenn Research Center at Lewis Field
Cleveland, OH 44135

Mr. Millis, is the founder and Project Manager of the Breakthrough Propulsion Physics Project. He has been with NASA's Glenn Research Center since 1982 after earning a degree in Physics from Georgia Tech. In addition to his more conventional assignments that have spanned engineering cockpit displays for micro-gravity aircraft trajectories, ion thrusters, control and monitoring systems for rockets, and cryogenic propellant delivery systems, he has conducted theoretical and experimental research on the possibility of creating propulsion breakthroughs. As a part of this research he forged collaborations with other researchers across the nation who work on similar long-range ambitions. In 1996 these efforts were formalized into the NASA Breakthrough Propulsion Physics Project. Mr. Millis is also an alumni of the 1998 Summer Program of the International Space University. He is presently pursuing a Masters degree in Physics Entrepreneurship at the Case Western Reserve University. In his free time he builds, photographs and writes articles on scale models, including science fiction models made from scrap plastic and 1960s vintage slot cars.

SAMPLE PUBLICATIONS:

Millis, M. G.**, "Prospects for Breakthrough Propulsion from Physics",** NASA TM-2004-213082 (May 2004). Summarizes the findings of 16 research tasks, where 6 were found not to be viable, 4 have clear opportunities for sequels, and 6 remain unresolved or have debatable findings.

Millis, M. G.**, "NASA Breakthrough Propulsion Physics Program",** In *Acta*

Astronautica, Vol. 44, Nos. 2-4, pp. 175-182, (1999).

Millis, M. G., "**Challenge to Create the Space Drive**", In *AIAA Journal of Propulsion and Power*, Vol. 13, N. 5, pp. 577-582, (Sep-Oct. 1997) Also available as NASA-TM-107289. Introduces seven hypothetical space drive concepts to identify the physics remaining to be solved that might enable such a breakthrough.

Millis, M. G. "**Breakthrough Propulsion Physics Workshop Preliminary Results**", In *Space Technology and Applications International Forum*, AIP Conference Proceedings 420, pp. 3-12, (Plenary Session III "Views of Future"), Albuquerque NM (Jan. 1998), and as NASA TM-97-206241 (Nov. 1997).

Millis, M. G., "**Design Factors for Applying Cryogen Storage and Delivery Technology to Solar Thermal Propulsion**", NASA TM-107379, Presented at the 1997 Space Technology and Applications Forum, Albuquerque, NM, January 26-30, 1997 (Report date: Dec. 1996).

Millis, M. G., & Williamson, G. S., "**Experimental Results of Hooper's Gravity - Electromagnetic Coupling Concept**", NASA TM-106963, AIAA-95-2601, 31st Joint Propulsion Conference, San Diego CA, (July 10-12 1995). Presents experimental results of testing a claim that self-canceling electromagnets would alter the weights of nearby objects. No effect was found within the detectability of the instrumentation.

Millis, M. G., "**Technology Readiness Assessment of Advanced Space Engine Integrated Controls and Health Monitoring**", NASA TM 105255, (1991) presented at 3 conferences: Conference on Advanced Space Exploration Initiative Technologies, Cleveland OH, (September, 4-6 1991), Third Annual Health Monitoring Conference for Space Propulsion Systems, Cincinnati OH, (November 13-14, 1991), and the Joint Propulsion Conference in Nashville TN (July 1992). 15 page paper : Defines minimum functions and features of an ICHM system, plus estimates the technology readiness and remaining development cost. It is a synthesis of two different contractor assessments (CR-187122 and CR-187123) which were based on the requirements outlined in NASA TM 103185.

Millis, M. G., (NASA Glenn Research Center), **Acceleration Display System for Aircraft Zero-Gravity Research**, NASA TM 87358, (March 1987). Documents the design, features, calibration, and testing of this system that was designed and built by

Millis in 1986. As of October 1995, this guidance system was still in use.

MILLIS SCIENCE FICTION:

Millis, M. G. "**Illustrative Example: Destination Mars**" [Fiction], In Hazards to Spaceflight, International Space University Summer Program 1998, Sec. 2.3, pp. 15-19 (1998). Copies available through http://www.isunet.edu.

Millis, M. G., "**Social Impact of Access to Space**" [Fiction], In Aerospace Frontiers (the internal news publication of NASA Glenn Research Center), Vol. 2, Issue 8 (August 2000).

SELECT MILLIS HOBBY PUBLICATIONS:

In his spare time, Mr. Millis builds, photographs and writes articles on scale models, including science fiction models made from scrap plastic. Most recently he completed the design and construction of a home slot car track (3-lane, 51.25ft). Here are examples of his published hobby works:

Millis,M., "**Your Tracks: Vintage Point Raceway**", In Model Car Racing, Issue 9, Vol. 2, N. 3, pp. 32-35, (May/June 2003).

Millis, M. G., "**Making Galileo Accurate**", In *Famous Spaceships of Fact and Fantasy, Second Edition*, Terry Spohn ed., Kalmbach Publishing Co., pp. 63-66, (1996). (A republish of an FSM magazine article from Nov. 1995.)

Millis, M. G., "**Scrap Building Fictional Models**", In *International Plastic Modeler's Society /USA Journal*, Vol. 7, Issue 2, p. 19-23, (January/February 1995). Explains the techniques developed by Millis for building science fiction models from scrap plastic such as tape dispensers, yogurt cups, coffee cream cups, printer cartridges, etc.

Millis, M. G., "**Building a Fantasy AeroTank in 1/25 scale**", In *Fine Scale Modeler*, Vol. 10, N. 1, p. 78-79, (January 1992). Discusses methods used to convert a telephone and other miscellaneous parts into a model of a futuristic hover-tank. Article includes a fictional write-up of the history and characteristics of the tank.

Millis, M. G., "**Lone Wolf**" (photo), In *Fine Scale Modeler*, Vol. 9, N. 7, p. 61, (November 1991). Awarded an Honorable Mention in a photo contest for a photo of a World War II German U-boat running at the surface at night-- a special effects photo of a 1/700 scale model atop plastic food wrap.

FULL PUBLICATION LIST

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Frequently Asked Questions

CONTENTS:

GENERAL INFORMATION:

Many questions we receive are already answered on the BPP web pages or can be found in existing textbooks or other literature. Also, your local university libraries or professors may be able to help you find answers to questions about the emerging physics.

For a general overview of the difficulties and emerging ideas for interstellar travel, visit
"Warp Drive, When?" at http://www.grc.nasa.gov/WWW/PAO/warp.htm

IF YOU WISH TO SUBMIT A RESEARCH PROPOSAL TO THE BPP PROJECT:

Please DO NOT SUBMIT any proposals or other materials for review. Unless research proposals are formally invited, the Breakthrough Propulsion Physics project does not have the means to review submitted materials. Please wait until research proposals are formally invited. If and when any invitations are issued, this news will be posted on this web site and in the *Commerce Business Daily*.

The previous call for BPP proposals closed February 26, 1999. Sixty proposals were received in this first solicitation, and selections were completed June 3, 1999. A summary of the tasks that received awards is available at: http://www.grc.nasa.gov/WWW/bpp/summ.htm

To prepare yourself for future calls for proposals, you may wish to study the scope and evaluation criteria of our previous call for proposals (http://www.grc.nasa.gov/www/bpp/NRA-99.htm). Similar criteria will be applied to any future research solicitations from the BPP project.

At the end of this standard reply are a list of CREDIBILITY CRITERIA which are used to screen proposals. If you are considering submitting future proposals or papers on this subject, you are STRONGLY advised to study and follow these criteria.

IF YOU WISH TO SUBMIT AN IDEA TO THE NASA BPP:

DO NOT SUBMIT any materials. Unless research concepts are formally invited, the BPP project does not have the means to review submitted materials. The NASA BPP project is not able to provide consulting services to individual researchers who need help checking or advancing their ideas. More submissions have already been received than can be read, let alone reviewed. Please wait until such submissions are formally invited.

Any individual who thinks they have a breakthrough device or theory is strongly advised to collaborate with a university or other educational institute to conduct a credible test of their claim. The university can propose (to the BPP Project) to conduct the test as an educational student project, where the students will learn first-hand about the scientific method and how to apply systematic rigor and open-mindedness in conducting a credible test of an incredible claim. In such collaborations it is suggested that the inventors retain full intellectual property rights to their devices or theories, and that the universities make the proposal and receive all the funds to conduct these student educational projects. With this procedure, if the device or theory works, then supporting evidence would be established in a credible fashion and the originator would retain the intellectual property rights. If the device or theory does not work, then at least the students would have had a meaningful educational experience, and the concept's originator can work on another idea.

At the end of this standard reply are a list of CREDIBILITY CRITERIA which are used to screen BPP submissions. If you are considering submitting future proposals or papers on this subject, you are STRONGLY advised to study and follow these criteria.

IF YOU ARE LOOKING FOR A SUMMER INTERNSHIP:

Step 1: Around November, go to www.oai.org
Step 2: Click on educational programs.
Step 3: Look for LERCIP links (LERCIP is the internship program).
Step 4: Either contact OAI by mail or download application.
Step 5: Fill out application and return it to OAI by January 31.
Step 6: Send an e-mail to: **Marc Millis**, via OAI, in January or February, alerting him that you have turned in an application.

IF YOU ARE LOOKING FOR A JOB:

There are no job opportunities open on this topic.

Funding of BPP research by NASA, other US government agencies, and private industry is still relatively small so there are limited job opportunities directly tied to BPP. Many BPP researchers work this topic part-time along with research on other areas and often devote their own time to work on BPP research. However, there are ways to prepare to conduct research in the BPP area.

To position yourself for future employment, seek a degree in Physics and/or Engineering, and seek any job where you can pursue such topics in your discretionary time. Being well versed in experimental methods and equipment is also an attractive characteristic to this endeavor. Also, stay tuned to the literature on this topic to learn who is doing what and where. Finally, stay tuned to see if the job situation changes.

For a list of current open positions at NASA, or to apply for a position at NASA, please view this web site: http://www.nasajobs.nasa.gov/.

CREDIBILITY SCREENING CRITERIA:

The following criteria will be used to screen proposals and papers submitted to the BPP Project. These criteria are based on normal scientific methods and specifically emphasize openness to visionary perspectives while still retaining the credible rigor necessary to make progress.

(1) Based on Credible References:
The work must be based in some way on data or theories that are in the peer-reviewed literature. References to conference or workshop papers are NOT considered peer-reviewed papers. The references must be from recognized peer-reviewed journals.

(2) Must Be Leading Toward a Discriminating Test:
The work must be leading to a discriminating test to determine if it accurately represents the physics of the effects being discussed. This implicitly requires that the work be compared to established interpretations and/or theories, so that the critical make-or-break issues can be identified. Reference citations for the established theories are mandatory. Also, the increment of work suggested must be consistent with the scientific method, with due consideration for the current status of the topic. Results of a discriminating test are preferred, but it is also sufficient that the work provide a design for a test or to simply identify the critical make-or-break issues for the immediate area of investigation.

(3) Overall Credibility:
To be considered as genuine progress, the results of any research must be accepted by other researchers as a credible foundation for future work. The conclusions must be sound and stay within the scope of the supporting evidence. Unresolved issues or uncertainty should be articulated, including error ranges on any experimental data. The methods used to reach the conclusions should be correctly employed. This includes mathematical correctness, correct descriptions for any cited works, citing the most relevant works, and sound experimental methods. Note that negative, credible test

results are also considered progress. For proposals, the research team should have a track record for producing credible work. The proposed work should be reasonable given the proposed costs.

(*) How These Criteria Map To Different Types of Papers:
The criteria above have been re-packaged below to address how they fit different types of reports and proposals:

(a) Benefit Analysis:
Any benefit analysis must cite devices, effects, or theories that are already in the peer-reviewed literature. They must summarize the current status of the approach they have chosen to explore. The scientific method levels can be used as a measure of maturity. This status summary should identify the critical make-or-break issues already identified in the prior literature. The analysis must be numeric (not just hand-waving), and must acknowledge the unknowns of the estimates in a credible manner. Predicted performance must be presented in a credible manner with due consideration for the large uncertainties and assumptions used to arrive at the predictions.

(b) Further Advancement of Published Theories:
In those cases where the author asserts that they are building upon work that is already in the peer-reviewed literature, they must cite that reference. They must also report some progress toward advancing the theory toward a discriminating test. They must identify the critical issues facing the correctness and utility of the theory. The utility of the theory to BPP must be clearly stated. They may illustrate the potential benefits of the theory to the problems of spaceflight, but must adhere to the criteria specified for benefit analyses stated above.

(c) New Theories:
In the case of new theories that are not yet in the literature, the author must cite peer-reviewed references for the PHENOMENON with which they are claiming consistency. It is not necessary that the author agrees with current interpretations of the data, but it is mandatory that the theories are consistent with the credible empirical evidence. It is also mandatory that the new theories be compared to the accepted theories that address the same phenomena. Reference citations for the contemporary theories are required. The comparison must explain how they differ to identify the critical make-or-break issues, and to advance the work closer toward a

discriminating test. It is mandatory that the new theories are at least matured to the point where mathematical models are offered. It is preferred that results of a discriminating test are presented, but it is also sufficient that the work describe the design of a test or simply identify the critical make-or-break issues for the immediate area of investigation.

(d) Further Investigation of a Confirmed Anomalous Effect:
An anomalous effect is defined as a physical phenomena whose characteristics are not describable by established theories. In cases where an anomalous effect is being discussed that has already been CONFIRMED in the literature, the author must cite peer-reviewed references that describe the effect. The author must explain why the effect might be advantageous to the BPP propulsion challenges. The expected next logical step would be to articulate a theory to describe the anomaly or to devise a means to apply the effect to solving BPP goals. If a new theory is presented, the criteria discussed above, for new theories, apply as well.

(e) Investigation of an Unconfirmed Anomalous Effect:
In cases where an anomalous effect is being discussed that has NOT YET BEEN CONFIRMED in the literature, it is mandatory that the author concentrates on the experimental methods for isolating the effect rather than speculating on a new theory to describe the unconfirmed effect. (No jumping to conclusions!) To demonstrate that the author is fully aware of why the effect is anomalous, they must cite references for the relevant current theories. The author must acknowledge possible conventional explanations of the anomaly, and the steps needed (or already taken) for a discriminating test. A discriminating test must be suggested that could distinguish between possible conventional explanations or whether this is a genuine new effect. In cases where the author is challenging negative test results that have already been published, the author must cite these references and explain why the prior tests were incomplete or why a reinvestigation is warranted. Also, the author must explain why the effect (if genuine) might be advantageous to the propulsion challenges.

THANK YOU AGAIN FOR YOUR INTEREST, AND FOR YOUR PATIENCE.

[Return to BPP homepage]

Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004.

Breakthrough Propulsion Physics Research Task Summaries

The following are summaries of the first five tasks that have been awarded funding from the BPP Project.Ê The selections were made in June 1999, and the awards were distributed among the chosen applicants around January 2000.

The results of the first year's progress were presented at the 37th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Salt Lake City, Utah, July 2001. Links to these papers are included in the reference lists at the end of each Task Summary.

The Tasks:

- Independent test of Woodward's transient inertia effect
- Investigation of quantum vacuum energy
- Test of electrodynamic torsion tensor theory
- Exploration of anomalous superconductor gravity effects
- Investigation of superluminal quantum tunneling

An Experimental Test of a Dynamic Mach's Principle Prediction

Principal Investigator: John G. Cramer, University of Washington, Seattle, WA

Relevance to BPP:
Directly relevant to a technologically desired effect for BPP Goal 1 (Mass)

Primary issue under investigation:
Is the transient inertia effect (utilizing a theoretical interpretation of MachÍs Principle) as published by Woodward in 1991, a genuine physical effect?

Planned completion date:
March 2001

Mach's Principle accounts for inertial reaction forces resulting from the gravitational attraction of all matter in the universe to an accelerating object. James Woodward of California State University at Fullerton has extended Sciama's 1953 demonstration that inertia can be understood as a gravitational effect in a linearized General Relativity framework. Woodward has shown that in addition to the acceleration dependent term that provides the basis for inertia, there is a time-dependent transient term. This term predicts that an object with a time-varying energy density will have a non-negligible variation in rest mass which depends on the second time-derivative of the energy.

Woodward has constructed an experiment which attempts to observe the predicted rest mass variations by vibrating a charging capacitor with a piezoelectric driver, and has reported measuring a mass variation in apparent qualitative confirmation of the predicted mass-variation effect. Results of these experiments, however, have been challenged in peer-reviewed literature due to the large number of uncontrolled variables in the methodology.Ê In particular, it seems possible that the applied vibrations coupled with non-linear mechanical responses of the system might lead to false positive observations.

The intent of this task is to perform an independent test of Woodward's inertial mass variation effect using methods that focus on the underlying critical issues and that avoid the limitations of Woodward's original experiments.

Such a mass variation, even if it is small, has interesting implications for propulsion. Acceleration appropriately phased with the mass variations might produce a net unidirectional force relative to the surrounding mass of the universe.Ê A spacecraft engine utilizing this principle would not require propellant, thus achieving the first mission of the Breakthrough Propulsion Physics project.Ê Even if the mass variation itself cannot lead to a propulsive effect, such a Machian mass variation is worth investigating.

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Woodward, J. F., Foundations of Physics Letters, Vol 5, pp.425-442 (1992)

Woodward, J. F., Foundations of Physics Letters, Vol 9, pp.247-293 (1996)

JPC 2001 BPP Session Paper:

Cramer, J., "Tests of Mach's Principle with a Mechanical Oscillator", AIAA Paper No. 2001-3908, Presented at the AIAA/SAE/ASME 37th Joint Propulsion Conf., Salt Lake City, UT, (July 2001)

Additional Conference Papers by Woodward:

Woodward, J. F., "Mass Fluctuations, Stationary Forces, and Propellentless Propulsion",Ê in Space Technology and Applications International Forum 2000, El-Genk, M. S., ed., American Institute of Physics, AIP Conference Proceedings 504, pp. 1018-1025 (2000)

Woodward, J., Mahood, T. and March, P., "Rapid Spacetime Transport and Machian Mass Fluctuations: Theory and Experiment",Ê AIAA Paper No. 2001-3907, presented at theÊ AIAA/SAE/ASME 37th Joint Propulsion Conf., Salt Lake City, UT, (July 2001)
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The Use of Surfaces in Systems to Exploit Quantum Vacuum Energy: A Theoretical Study Using QED (Quantum Electrodynamics) Coupled with an Experimental Study Using MEMs (Microelectromechanical) Devices

Principle Investigator: Jordan Maclay, Quantum Fields LLC, Richland Center, WI,
in collaboration with:
Rod Clark and Jay Hammer, MEMS Optical, Inc., Huntsville AL
Prof. Michael George and Lelon Sanderson, University of Huntsville, AL,
Consultants:
Peter Milonni, Los Alamos National Laboratory
Robert Forward, Forward Unlimited
Carlos Villarreal, National Univierstiy of Mexico
Michael Serry, Digital Instruments

Relevance to BPP:

Make-break issues underlying desired effects for BPP Goals 1 (Mass) and 3 (Energy)

Primary issue under investigation:
Existence of, magnitude of, and ability to interact with quantum vacuum energy.

Planned completion date:
December 2002

Quantum Electrodynamics (QED) is probably the best verified theory in physics. It makes some startling predictions about the importance of quantum fluctuations of the electromagnetic field in empty space. It predicts a near infinite vacuum energy density. Quantum fluctuations have been linked to particle mass, to spontaneous emission, to the speed of light, and to the topology of the universe. Since the presence of surfaces will change the energy density of the vacuum, surfaces can be used to alter parameters affected by vacuum fluctuations. The ability to alter these parameters could be of significant benefit to the BPP objectives. We will perform a theoretical investigation of the use of surfaces and cavity structures in order to alter vacuum energy. A microelectromechanical (MEMS) interferometric structure is planned to measure the index of refraction in a cavity, which will serve as a test of QED predictions.

The variations in vacuum energy produced by surfaces can also result in vacuum forces, such as the recently verified Casimir force between two parallel conducting plates. Very few other geometrical structures have been investigated, and our understanding of the role of surfaces in altering vacuum energy and generating vacuum forces is rudimentary. For rectangular cavities, forces are predicted on the walls that may be inward, outward, or zero, depending on the ratios of the sides. Such forces may be of use in operating MEMS devices, including resonant cavities. We propose to model and build a MEMS cavity structure, to verify the QED prediction of repulsive forces, and to study the properties of these cavities and the energy balance in a static and in a vibrating mode. When we have gained a greater understanding of cavities and vibrating structures, a second-generation MEMS structure will be designed, modeled, fabricated, and tested.

We will investigate the possibility of fluctuation-driven engines that operate between two regions of different energy density, in a similar manner to which heat engines operate between two heat reservoirs at different temperature. Two types of engine will be considered: one in which one set of surfaces moves relative to another, akin to an electric motor, and a second type in which a working fluid, perhaps consisting of atoms or electrons, passes between the two regions of different vacuum energy. We will develop several candidate structures for fluctuation engines and fabricate the most promising. In all theoretical and experimental work, care will be taken to understand energy balance requirements and conservation laws, and to determine what is possible and what is not. QED computations will be used as the guide.

This effort will answer many of the basic questions about the role of vacuum fluctuations, and lay a solid foundation of knowledge about vacuum energy, vacuum stresses and how to control them using surfaces and what their limitations are. Researchers will be able to build upon this knowledge to build more complex ideas and structures involving vacuum fluctuations.

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Research and Development in Vacuum Fluctuations at Quantum Fields, LLC.
Note: This link will take you out of the NASA domain.Ê If you wish to return to this NASA site, use your browser's "back" feature.

JPC 2001 BPP Session Paper:

Maclay, J.,Ê Hammer, J., Clark, R., George, and M., Sanderson, L., "First Measurement of Repulsive Quantum Vacuum Forces", AIAA Paper No. 2001-3359, Presented at the AIAA/SAE/ASME 37th Joint Propulsion Conf., Salt Lake City, UT, (July 2001)
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Search for Effects of an Electrostatic Potential on Clocks in the Frame of Reference of a Charged Particle

Task Leader and Co-Principal Investigator: Harry I. Ringermacher, Kronotran Enterprises, LLC, Delanson, NY
Co-Principal Investigator: Mark S. Conradi, Washington University, St. Louis, MO

Brice N Cassenti, United Technologies Research Center, East Hartford, CT

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Relevance to BPP:
Make-break issue underlying a desired effect for BPP Goal 1 (Mass)

Primary issue under investigation:
Test theory linking electromagnetism with spacetime which includes asymmetric components.

Planned completion date:
January 2001

A new theory that self-consistently imbeds classical electrodynamics within the framework of non-Riemannian space-time, by way of introduction of an electrodynamic Torsion tensor into Einstein's equations, has been formulated and its field equations solved. The theory predicts that an intense, external electrostatic potential should measurably shift the internal clock of a charged particle analogously to the gravitational red shift. The internal clock refers to time as seen by a particle of charge-to-mass ratio, e/m, in its rest frame. We propose a nuclear magnetic resonance experiment to measure the influence of the electrostatic potential on the precession rate (clock) of a proton magnetic moment. The first of two definitive papers describing the theory has already been published [Ringermacher 94]. Metric solutions of Einstein's field equations result in the correct electromagnetic potentials appearing in the metric tensor for several cases including spherical gravity plus electrostatic field, the line charge electric field, and the uniform magnetic field. The latter two solutions are exact. All of the solutions have been shown to satisfy a general equivalence principle including both attractive and repulsive forces resulting from two signs of charges.

Since the electromagnetic 4-vector potential (the scalar potential in g00) appears as the solution in the metric, much like the gravitational potential in the usual gravity theory, an experimental prediction is proposed that an electrostatic potential influences clocks in much the same way as gravitational potentials with one major difference: these solutions are in the frame of reference of the charged particle. Such a clock, which will be referred to as a charged clock, is arbitrary, much like a quantum phase, and will not influence measurable events. Only time differences could be measured. The application of nuclear magnetic resonance (NMR) offers an opportunity to synchronize charged clocks and subsequently read out changes arising from the application of intense electrostatic potentials during the NMR process. NMR is a natural way to read charged clocks since the NMR effect is itself induced in the rotating frame of the charged particle, in this case, a proton with a magnetic dipole moment (spin). The ideal effect, for a fully "supported" proton subjected to a l0-kV electric field, is expected to generate a frequency spectral line shift (equivalent to a shift in time) on the order of 6 ppm and broadening for a sharp proton resonance. This is easily measurable in a typical high resolution NMR spectrometer. The size of the actual measured effect will depend on the final choice of experimental conditions representing, as closely as possible, a "supported proton." A complementary NMR experiment would measure the effects of potential difference alone under zero field condition.

If this theory is proven, then there may exist solutions where electromagnetism can dynamically couple to space, time, and gravity, either explaining existing effects or predicting new ones. In particular, such solutions could be applied to the goal of creating propulsive effects.

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Interim Publications:

Cassenti, B. N., and Ringermacher, H. I., "Engineering Warp Drives", in Space Technology and Applications International Forum 2000, El-Genk, M. S., ed., American Institute of Physics, AIP Conference Proceedings 504, pp. 1085-1092 (2000)

JPC 2001 BPP Session Paper:

Ringermacher, H.,Ê NY,Ê Conradi, M., Browning C., and Cassenti, B., "Search for Effects of Electric Potentials on Charged Particle Clocks", AIAA Paper No. 2001-3906, Presented at the AIAA/SAE/ASME 37th Joint Propulsion Conf., Salt Lake City, UT, (July 2001)
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Exploration of Gravity Modification by Josephson Junction Effects in Magnetized High-Tc Superconducting Oxides

Principal Investigators: Glen A. Robertson and Ron R. Litchford, NASA Marshall Space Flight Center, Huntsville, AL
Consultant: Randall Peters, Mercer University

Relevance to BPP:
Make-break issues underlying a desired effect for BPP Goal 1 (Mass)

Primary issue under investigation:
Explore the validity of unconfirmed observations and theoretical speculations of gravitational effects using YBCO superconductors & electromagnetism.

Planned completion date:
February 2001

In response to the propulsion challenges specified by NASA's Breakthrough Propulsion Physics (BPP) project, the NASA Marshall Space Flight Center proposes to empirically explore the possibility of inducing gravity modification through Josephson junction effects in magnetized, high-Tc superconducting oxides. Our technical goal is to critically test emerging physical concepts and provide rigorous empirical confirmation (or refutation) of anomalous effects related to the manipulation of gravity by magnetized type-II superconductors. Because the current empirical evidence for gravity modification is anecdotal, we propose, as a first step, to design, construct, and meticulously carry out a discriminating experiment. We will construct an extremely sensitive torsional gravity balance to measure gravity modification effects by radio-frequency-pumped type-II superconductor test masses. Analysis indicates that an effective change in mass of less than 1 percent would be readily detectable by state-of-the-art differential capacitance transducers.

If uncontested positive effects can be detected, it would seem to imply a fundamentally new effect that might ultimately lead to creating motion without propellant.

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Robertson, G. A., "Search for a Correlation Between Josephson Junctions and Gravity", in Space Technology and Applications International Forum 2000, El-Genk, M. S., ed., American Institute of Physics, AIP Conference Proceedings 504, pp. 1026-1031 (2000)

JPC 2001 BPP Session Paper:

Robertson, T., "Exploration of Anomalous Gravity Effects by rf-Pumped Magnetized High-T Superconducting Oxides", AIAA Paper No. 2001-3364, Presented at the AIAA/SAE/ASME 37th Joint Propulsion Conf., Salt Lake City, UT, (July 2001)

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SUBSEQUENT FINDINGS BY OTHERS:

Hathaway, Cleveland, and Bao, "**Gravity modification experiment using a rotating superconducting disk and radio frequency fields**", *Physica C*, **385** (2003), pp. 488-500.

This privately funded replication of the Podkletnov configuration: "found no evidence of a gravity-like force to the limits of the apparatus sensitivity," where the sensitivity was "50 times better than that available to Podkletnov."Ê Therefore, this rotating, RF-pumped superconductor approach is considered non-viable.

Detection of Superluminal propagation at low or near resonance frequencies and the dynamics of the Forerunners

Principle Investigator: Kevin Y. Malloy, University of New Mexico, Albuquerque, NM
Co-Investigator: Mohammad Mojahedi, University of New Mexico, Albuquerque, NM
Co-Investigator: Raymond Chiao, Univ. of California at Berkeley, CA

Relevance to BPP:
Underlying general physics related to a make-break issue for BPP Goal 2 (Speed)

Primary issue under investigation:
Addresses the faster-than-light hypotheses of quantum tunneling, particularly in the case of amplification in the tunnel barrier.

Planned completion date:
February 2002

In recent years, the subject of superluminal propagation has received much attention. A complete review of this field is provided in reference [1]. At the present, a body of experimental evidence [2-7] suggests the reality of superluminal group velocities for tunneling photons (and perhaps electrons); however, there is no universal agreement on the interpretation of these facts. In all of the above experiments, the magnitude of the incoming wave is attenuated upon tunneling and consequently the energy velocity remains subluminal. [8].

In principal, a rather more striking superluminal behavior can be exhibited in the case of inverted medium.Ê [By "inverted medium" it is meant that the tunnel region is made such that it can amplify the signal.]Ê Under special circumstances photons can travel through an inverted medium with phase, group, energy, and signal velocities all exceeding the velocity of the light in vacuum [1, 9]. This phenomenon can occur either at low frequencies or at frequencies close to resonance. While the low- frequency behavior is easier to understand (the index of refraction becomes less than 1), the higher frequency response can be understood in terms of tachyon-like excitation process, in which undamped atomic polarization waves are strongly coupled to electromagnetic waves. This phenomenon is different in nature from the previously studied tunneling effects and in principal can be observed over long distances. While the theoretical foundation for the above anomalous effect is well established [9], as to date, there has not been any experimental verification.Ê [See "Note" below regarding the recent NEC work, published after the start of this task.]Ê We propose exploring the above possibility via experiments with inverted media such as fiber amplifiers or rubidium vapor. Since both the low frequency and the tachyonic propagation involves exchange of energy between the wave and matter resulting in superluminal energy velocities, it is perhaps necessary to redefine energy velocity such that this rather anomalous effect is properly explained [10].

It is believed that in all superluminal propagation (low frequency, tachyonic or tunneling), the very front of the optical or microwave signal shall remain luminal in order to properly address the requirements of the special relativity and causality. Therefore, a careful investigation of these early parts of the signal, so called "forerunners" is of tremendous importance in regard to propulsion "make-or-break" issues. The form of the forerunners is dictated by the details of the dispersion relation and the incoming wave. Since in our tunneling experiments and many others, the optical multi-layers, also known as one dimensional photonic crystals (1DPC), are used [11], it is natural that we investigate the dynamics of forerunners for this particular structure. In this proposal, we envision a theoretical formulation of the forerunner's field and the possible experimental detection of these fields for the case of 1DPCs. Clearly, a correct mathematical formulation of the forerunners and possible consequent detection of these disturbances strongly suggests that, regardless of superluminal observation of group, signal, or even energy velocity, the requirements of causality is fully observed, and no violation of principal axioms are allowed.

Although it is premature and non-scientific at present to suggest a detailed and direct connection between the proposed tasks and possible future BPP devices, the suggested tasks are in close correlation with the expressed desire of "conducting experiments or advancing theories that address critical unknowns, make-or-break issues or curious effects." In other words, while the proposed ideas are far from becoming breakthroughs in near future, they provide a starting point for scientifically assessing the ideas regarding the application of these anomalous effects to propulsion physics.

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ÊÊÊ [First direct time-domain measurement of superluminal group velocities for microwave pulses through one-dimensional photonic crystals.]

Mojahedi, M., Schamiloglu, Kamil,, and Malloy, "Frequency Domain Detection of Superluminal Group Velocities in a Distributed Bragg Reflector", *IEEE Journal of Quantum Electronics*, **36** (2000), pp. 418-424.

Segev, B., Milonni, Babb, and Chiao, "Quantum noise and superluminal propagation", *Physical Review A*, **62** (2000), pp. 0022114-1 - 0022114-15.

JPC 2001 BPP Session Paper:

Mojahedi, M., Malloy, K., and Chiao, R., "Superluminal but Causal Wave Propagation", AIAA Paper No. 2001-3909, Presented at the AIAA/SAE/ASME 37th Joint Propulsion Conf., Salt Lake City, UT, (July 2001)

Note:
Regarding the publicized work of L. J. Wang, et. al. at NEC Research Institute, in which the authors were able to observe "Gain-Assisted Faster-than-c Light Propagation":Ê The theoretical foundation and experimental approach for this experiment was proposed earlier by Raymond Chiao as:Ê "Population inversion and superluminality," in Amazing Light: a volume dedicated to Charles Hard Townes on his 80th birthday (Springer-Verlag, New York, 1996), p. 91-108.Ê In ChiaoÍs proposal and its later implementation, effects such as electromagnetic induced transparency (EIT) made the chosen gain medium (rubidium vapor) inappropriate; In the case of WangÍs experiment, cesium vapor was used for this the purpose.
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AIAA-2001-3908

Tests of Mach's Principle with a Mechanical Oscillator*

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Abstract

James F. Woodward has made a prediction, based on Sciama's formulation of Mach's Principle in the framework of general relativity, that in the presence of energy flow the inertial mass of an object may undergo sizable variations, changing as the 2nd time derivative of the energy. We describe an attempt to observe the predicted effect for a charging capacitor, using a technique that does not require a reactionless force or any local violation of Newton's 3rd law of motion. We attempt to observe the effect of the mass variation on a driven harmonic oscillator with the charging capacitor as the oscillating mass. Positive and negative phase shifts in the oscillator motion with respect to the driving force are predicted to result from appropriately programmed inertial mass variations. The phase shift is constant, so that data may be accumulated over a very large number of oscillation cycles to insure high precision in the phase shift determination. We report on the predicted effect and the design and implementation of the measurement apparatus. At this time, however, we will *not* report on observations of the presence or absence of the Woodward effect.

Introduction

This is a status report on a new experiment to test a prediction based on general relativity and Mach's Principle, which has been supported by the Breakthrough Propulsion Program of NASA.

Einstein's Principle of Equivalence, a cornerstone of general relativity, asserts the exact universal identity of inertial mass and gravitational mass. However, the origins of inertia and its connection to gravitational mass remain obscure. Mach's Principle, the idea that inertia originates in the gravitational interaction of massive objects with the distant matter of the universe, is an attempt to unify gravitational and inertial mass, but it is not a part of general relativity. Dennis Sciama [1,2] attempted to improve this situation by showing that, for sufficiently symmetric and homogeneous universes, the gravitational interaction of massive objects with distant matter leads to an acceleration-dependent force, i.e., inertia.

James F. Woodward [3,4] extended Sciama's calculations by introducing energy flow (e.g., the energy flowing to a charging capacitor) into the gravitating system. He demonstrated that the equations acquire extra transient contributions in Sciama's inertia term that are proportional to 1/G (Newton's gravitational constant) and therefore are quite large. The implications of this work are: (a) that it may be possible to modify inertia, and (b) that it may be possible to demonstrate the validity of Mach's Principle with a tabletop experiment.

Woodward and his students [4-7] have attempted to observe the predicted inertia-variation effect by accelerating a mass-varying object so that it produces a reactionless force. To illustrate this, assume that an inertia-varying test mass is accelerated to the right when it has low inertia and to the left when it has high inertia. In this circumstance, it is argued, the reaction forces of the two accelerations are unequal and one might expect the net reactionless force to "row" the system to the right. Woodward's group reports [7] using a sensitive torsion balance to observed small reactionless forces at magnitudes that are near the limits of their sensitivity and about five orders of

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magnitude smaller than the predicted effect (see the calculations below.)

Unfortunately, this scheme for observing the predicted inertia variation appears to be at odds with the relativistically invariant form of Newton's 2nd law of motion:

$$\vec{F} = d\vec{p}/dt = m\, d\vec{v}/dt + \vec{v}\, dm/dt \quad (1)$$

Since the inertial mass **m** of the test body is expected to vary with time, the last term of Eqn. (1) cannot be ignored. It is not surprising, in view of Newton's 3rd law of motion, that for any closed cycle of acceleration and variation of the inertial mass around a central value, the force contribution from the **v dm/dt** term is found to precisely cancel the supposed "reactionless force" arising from the **m dv/dt** term, leading to a net force of zero for the overall system.

From this simple calculation, it appears that reactionless force searches are ***not*** good tests of the proposed effect. There remains the question of whether the Woodward inertia variation is indeed present in a system with energy flow. We have found, as will be described below, that a mechanical oscillator, driven at resonance, with its mass programmed to vary at the drive frequency, shows sensitive variations in drive-to-response phase and amplitude, depending on the relative phase between the mass variation and the oscillator drive.

Theory

Woodward has shown [5] that the relativistically invariant wave equation, in the simplest approximation and expressed as a function of an overall scalar gravitational potential ϕ, has the form:

$$\nabla.\phi - (1/c^2)(\partial^2\phi/\partial t^2) = \quad \phi = 4\pi G\rho_o + (\phi/\rho_o c^2)(\partial^2\rho_o/\partial t^2) - (\phi/\rho_o c^2)^2(\partial\rho_o/\partial t)^2 \quad (2)$$

where G is Newton's gravitational constant, ρ_o the rest mass density, and c the speed of light. This field equation is obtained only if one assumes, as suggested by Mach's Principle, that the local energy density of matter is equal to the matter density times ϕ. Since Mach's Principle demands that $\phi = c^2$ when measured locally, this constraint is equivalent to asserting that $E = mc^2$. Additional terms would be present in this equation were it not for the fact that, as a consequence of Mach's principle in this approximation, $\phi = c^2$.

In writing Eqn. (2), Woodward neglects a term of the form $c^{-4}(\partial\phi/\partial t)^2$ because it is always small, given its c^{-4} coefficient that is not compensated for by any factor of ϕ in the numerator. Combining the last three terms of Eqn. (2) into an effective mass density $\rho(t)$ and solving for this quantity gives the time-dependent effective mass density as:

$$\rho(t) \approx \rho_o + (1/4\pi G)[(\phi/\rho_o c^2)(\partial^2\rho_o/\partial t^2)] - (1/4\pi G)[(\phi/\rho_o c^2)^2(\partial\rho_o/\partial t)^2]. \quad (3)$$

The second term in Eqn. (3) has the form $(1/4\pi G)[(\phi/\rho_o c^2)(\partial^2\rho_o/\partial t^2)]$. This time-dependent fluctuation in the inertial mass can be both positive and negative when ρ_o undergoes periodic time variations, e.g., when a varying flow of mass-energy is present. This is the inertia-varying term of interest.

In the present work we will ignore the last time-dependent or "wormhole" term, which has the form $-(1/4\pi G)[(\phi/\rho_o c^2)^2(\partial\rho_o/\partial t)^2]$. This mass term is always negative or zero and for sinusoidal variations is about 0.1% or less of the other terms.

If a capacitance **C** is driven by a voltage source with time dependent potential $V(t) = V_0 \mathrm{Sin}(\omega t)$, then the energy in the capacitor, assuming dissipative and inductive effects can be neglected, is $U(t) = ½C\, V(t)^2 = ½C\, V_0^2 \mathrm{Sin}^2(wt)$. The second time derivative of this stored energy divided by c^2 (to convert it to a mass) is $d^2U/dt^2 = C\, V_0^2\, \omega^2\, \mathrm{Cos}(2\omega t)/c^2$. This is the $(\partial^2\rho_o/\partial t^2)$ factor in Woodward's Eqn. (3). The corresponding time dependent variation in inertial mass, assuming that $\phi = c^2$, is then:

$$dm(t) = 1/(4\pi\rho_o G\, c^2)\, C\, V_0^2\, \omega^2\, \mathrm{Cos}(2\omega t). \quad (4)$$

We will use this form for the variation in inertial mass in the analysis that follows.

To give this prediction a scale, let us assume that c=2.998×10^8 m/s, G=6.672×10^{-11} m^3/kg s^2, ρ_0=2,000 kg/m^3, C=9.3×10^{-9} F, V_0=2,000 V, and ω=2π×1,000 Hz. With these values, we find that:

$$dm(t) = 9.7 \text{ mg} \times \mathrm{Cos}(2\pi \times 2{,}000 \text{ Hz} \times t). \quad (5)$$

In other words, under these conditions, which should be realizable in the experiment described here, the inertial mass of the capacitance is predicted to vary by about ±10 milligrams at *twice* the capacitor charging frequency, or 2,000 Hz. If the mass of the capacitor and its holder were about 1 g, this would represent a mass variation of about ±1%. Such a mass variation would have large observable consequences. However, we note that Woodward [4] has made arguments involving mobile charges to explain why the actual variation in the inertial mass may be orders of magnitude smaller than that predicted by simple calculations and more consistent with his reported observation of very small reactionless forces.

It is also of interest to consider the maximum current flow that is necessary to charge the capacitor in the manner assumed above. The charge on the capacitor is **q=C V(t)**, so the charging current is $\mathbf{i(t) = C\, dV/dt = C\, V_0\, \omega Cos(\omega t) = 116\ mA \times Cos(\omega t)}$ for the specified conditions. It turns out that a high voltage power supply/amplifier capable of delivering an audio-frequency peak current of a few hundred milliamps at a few kilovolts is very expensive (~$14,000) and represent the most costly component required for the present test of the Woodward effect.

A Driven Mass-Varying Oscillator

We test for the presence of the Woodward effect by using the capacitor as the mass in a system that forms a driven mechanical mass-and-spring oscillator with an undriven resonant frequency of $\boldsymbol{\omega_0}$. Such an oscillator is shown schematically in Fig. 1

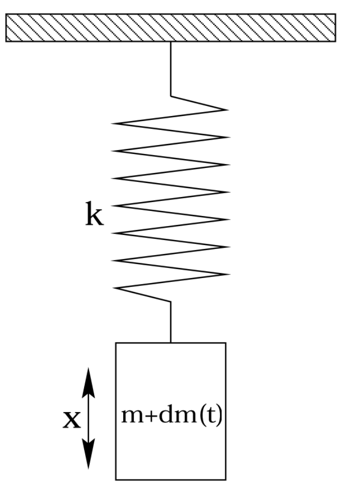

Figure 1. Schematic mass-and-spring mechanical oscillator with time varying mass **m+dm(t)** and restoring-force spring constant **k**. The system is assumed to have a dissipative damping force of $\mathbf{-b\, dx/dt}$.

The oscillator is driven at its resonant frequency $\boldsymbol{\omega_d = (\omega_0^2 - b/2m)^{1/2}}$ with a voice coil actuator and audio amplifier. At the same time, we charge the capacitor sinusoidally, using approximately the parameters specified above, at a frequency of $\boldsymbol{\omega_d/2}$ so that, in the presence of the Woodward effect, the capacitor's inertial mass should vary at frequency $\boldsymbol{\omega_d}$.

The inhomogeneous non-linear differential equation describing such a system is:

$$F_d Cos[\omega_d t] = kx(t) + [b + \mu'(t)]x'(t) + [m + \mu(t)]x''(t), \qquad (6)$$

where **x(t)** is the motion of the capacitor, $\mathbf{F_d}$ is the magnitude of the driving force, $\boldsymbol{\omega_d}$ is the angular frequency of the driving force, **k** is the Hooke's law restoring force constant, **b** is the damping constant representing dissipative forces in the system, **m** is the average mass of the capacitor and associated structure, and $\boldsymbol{\mu(t)}$ is the time-dependent mass variation due to the Woodward effect. Note that the $\boldsymbol{\mu'(t)x'(t)}$ term in Eqn. (6) arises from the **v dm/dt** term in Eqn. (1).

We can replace the spring constant **k** with $\mathbf{m\, \omega_0^2}$ and replace $\boldsymbol{\mu(t)}$ with $\boldsymbol{\mu_0 Cos(\omega_d t + \phi_m)}$, which assumes that we have arranged the mass variation to be at the same frequency as the driving force but shifted in phase by $\boldsymbol{\phi_m}$. With these substitutions, Eqn. (6) becomes:

$$F_d Cos(\omega_d t) = m\omega_0^{\,2} x(t) + [b - \mu_0 \omega_d Sin(\omega_d t + \varphi_m)]\, x'(t) + [m + \mu_0 Cos(\omega_d t + \varphi_m)]x''(t) \qquad (7)$$

This non-linear differential equation has no analytic solutions and must be solved numerically. Fig. 2 shows the results of such numerical solutions of Eqn. (7), assuming that $\mathbf{F_d/m}$=0.01, **b/m**=0.01, and $\boldsymbol{\mu_0}$**/m**=0.001. The latter assumption represents only about 10% of the predicted 10 mg mass variation.

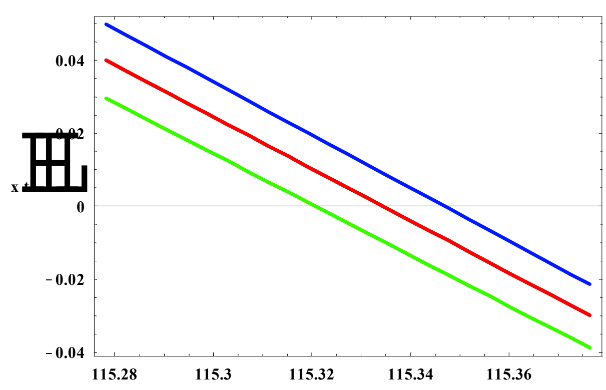

Figure 2. Response phase shifts of the system to variable mass. The central line is the system response with μ_0=0. The other two lines represent μ_0=0.001 with $\phi_m = -\pi/2$ (low), and $\phi_m = +\pi/2$ (high). The phase shifts shown are about ±0.04 radians=±2.3 degrees.

We find that when the mass variation has a relative phase of $\pm\pi/2$ with respect to the driving force, it causes a positive or negative phase shift in the response motion by shifts, using the values listed above, of several degrees. Other phases near 0 or π can cause an increase or decrease in the amplitude of oscillation. The experiment we have constructed is designed in an attempt to observe these phase-shift effects.

Experimental Apparatus

Fig. 2 below shows a top view of the mechanical oscillator arrangement, which we call the “Mach Guitar”. The barium titanate capacitor test mass is suspended between pairs of tensioned wires, with the tension adjusted so that the resonant vibration frequency for vertical oscillations is about 1-2 kHz.

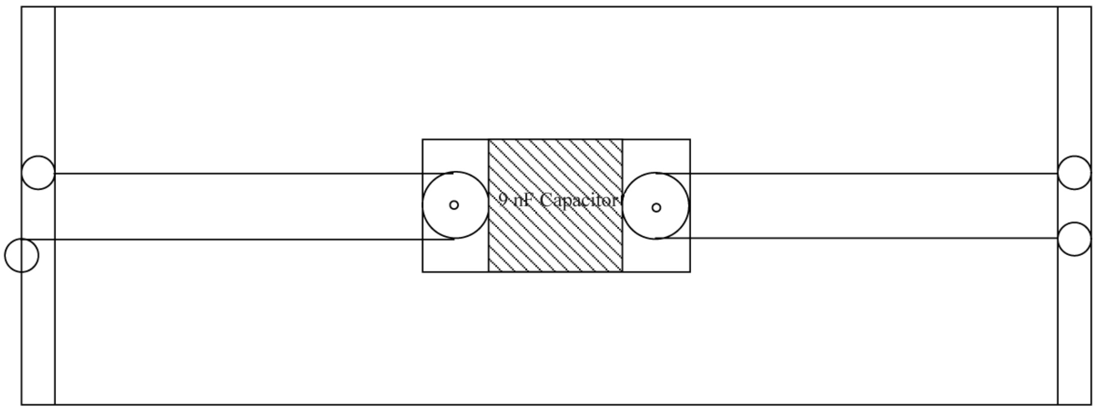

Figure 2 Top view of “Mach Guitar” arrangement. The capacitor is suspended between pairs of tensioned wires that provide the restoring force for the mechanical oscillator. Capacitor drive voltage is supplied through the wires.

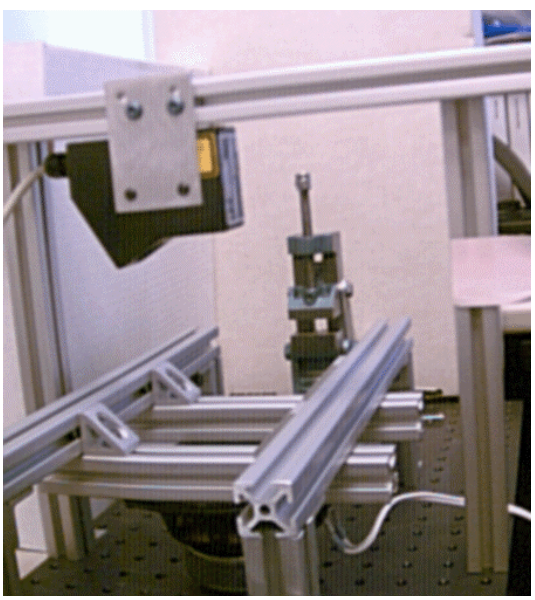

Figure 3 Laser-optics table with oscillator removed, showing voice-coil drive (below) and laser position monitor (above).

Electrical connections for the capacitor drive voltage are supplied through the tensioned wire pairs. The capacitor and its support structure have a net mass of about 1 g.

The restoring force provided by the tensioned wire pairs is $\mathbf{F=-(8T/L)x}$, where $\mathbf{T}$ is the tension in a given wire, $\mathbf{L}$ is the overall length, from bridge to bridge, of the system, and $\mathbf{x}$ is the vertical displacement of the capacitor. Therefore, neglecting the mass of the wire, the resonant frequency of the oscillator is $\boldsymbol{\omega_0=(8T/mL)^{1/2}}$. If $\mathbf{m}$=1 g, $\mathbf{L}$=0.5 m and $\boldsymbol{\omega_0}=2\pi \times 1000$ Hz, then the required tension is 553 lb. This tension can be reached with 13 gauge steel wire.

Fig. 3 shows a view of the laser-optics table (with oscillator removed) that is the foundation of the experiment. A pre-drilled aluminum laser-optics base plate supports the general-purpose aluminum beam structures, on which are mounted (below) the voice-coil drive (a modified audio speaker) for the mechanical oscillator, and (above) the laser position-measuring device shown in Fig. 4.

The Mach Guitar is mounted on the laser-optics base, which provides “bridges” to support for the wires and their tensioning mechanism. Electrical connections to the capacitance are made through the support wires. Below the oscillator is an audio speaker, which drives the oscillator through a light spring. Above the oscillator is a commercial laser position detector, which measures the vertical position of the capacitor's upper surface by electronic triangulation. The laser position sensor is shown in Fig. 4

Fig. 4 Laser position measurement device.

The mass-varying object used in the measurements is a low-loss and low-mechanical-movement barium titanate capacitor with a capacitance of about 9 nF and a voltage rating of 3 kV. This oscillator mass is suspended between pairs of 13 gauge steel wires (0.25 m long on each side) that have been tensioned to about 500 lb to provide a system resonant frequency of about 1000 Hz.

Fig. 5 Trek Model PO923A HV Power Amplifier, used for driving the capacitor at 2 kV and 400 mA.

As previously mentioned, the most challenging problem presented by the present experiment is driving the capacitor to high voltages at audio frequencies. The reason is that all high-voltage amplifiers driving capacitive loads are severely limited by the charging current that they must deliver. We have selected a Trek Model PO923A High Voltage Power Amplifier, shown in Fig. 5, as the capacitor driver. It can drive at voltages up to 2 kV with a peak charging current of up to 400 mA.

The Mach's Principle test employs a Pentium-2 850 MHz computer system with a Windows 98 operating system for experiment control, using control software based on LabView. It consists .of controls for the mechanical oscillator driver and the capacitance driver, a data collection system that records the drive signal and the position measurements, a data recording and retrieval system, and analysis software for processing the data and extracting the phase information of interest.

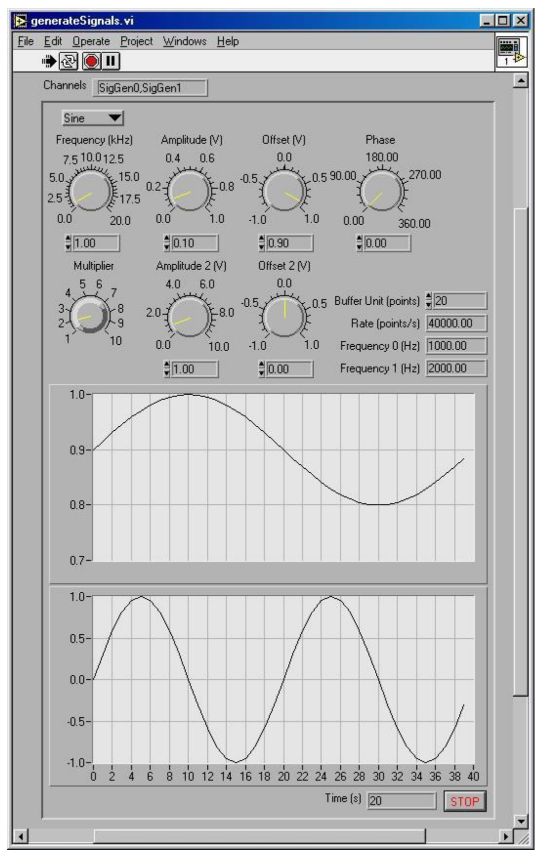

Figure 6. LabView control panel and display for system drivers.

The LabView control panel and display for the experiment is shown in Fig. 6 above. The system generates sine waves with adjustable phases and amplitudes at two frequencies, normally set to differ by a factor of two. The low frequency signal provides the input to the high voltage amplifier that drives the capacitor. The high frequency provides input to an audio amplifier connected to a voice coil that drives the mechanical oscillator.

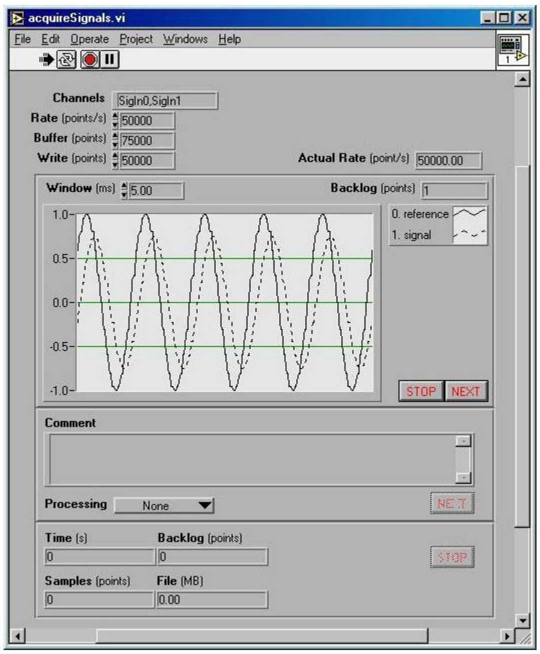

Figure 7. LabView data acquisition and display.

Figure 7 shows the LabView panel for the data collection system. The system samples the mechanical drive voltage and the capacitor position measurement of the mechanical oscillator as separate data streams. These are sampled for real-time display and also recorded on the system hard disk. These data streams can be read back and re-analyzed. The data are analyzed by integration over a long time period to extract the relative phase of the drive and response signals for a given setting of the capacitor drive phase with respect to the mechanical driver.

The processed quantity that will be accumulated in the analysis is the cosine of the relative phase between the driving signal **D(t)** and the mechanical response signal **R(t)**. There are a variety of ways of extracting this signal, but the one we will use initially is:

$$Cos(\varphi) = \frac{\int_0^T [D(t)+R(t)]^2 dt - \int_0^T [D(t)-R(t)]^2 dt}{4\sqrt{\int_0^T D(t)^2 dt \times \int_0^T R(t)^2 dt}} \qquad (8)$$

Here **T** is an arbitrary integration time that increases as data is collected and the running integrals are accumulated. The values of **Cos(ϕ)**, which is near 0 because ϕ is approximately **π/2** on resonance, will be compared for the two most extreme settings of the phase of the capacitor drive, which should produce phase shifts like those shown in Fig. 2. We estimate that with a data collection cycle of a few hours, **Cos(ϕ)** can be determined to an accuracy of a few parts in 10^5. This should enable us to determine the shift in ϕ to similar accuracy, providing a fairly stringent test of the presence or absence of the Woodward mass variation.

Experiment Status

The experiment is presently being reconfigured on the laser-optic table. The initial cantilever arrangement is being replaced with the new “Mach guitar” mechanical oscillator system described above.

The previous mechanical oscillator, which used a capacitor mass suspended at the free end of an aluminum cantilever, was tested and found to present three serious problems for the experiment: (1) its resonant frequency was fixed by the length and mass of the cantilever and was not easily adjustable, (2) The cantilever mass dominated that of the capacitor, greatly reducing the magnitude of the predicted effect and (3) it was not capable of achieving resonant frequencies above a few hundred Hz. Since the size of the predicted mass-variation effect increases as $\boldsymbol{\omega_0^2}$, this was a serious limitation. However, initial experience with this cantilever oscillator provided valuable experience in operating and testing the position measuring device and the data collection system.

The new Mach Guitar oscillator provides significant improvements over the cantilever in reduced mass and increased operating frequencies, and it offers the additional advantage that it is easily tunable through simple adjustments of the wire tension.

We expect to begin data collection with the new configuration in the next few weeks.

Conclusion

The test of Mach's principle and the Woodward effect described above is not yet completed, but it shows promise of providing an independent test of the predictions that does not depend on the possibility of a reactionless force. The experiment in the present configuration is not as sensitive as the torsion-balance measurements recently reported by Woodward [7]. However, since it is not based on a reactionless force, it may not need that sensitivity.

If the Woodward Effect is observed, it will have important implications for general relativity and cosmology, for validating Mach's Principle, for control of inertia, and possibly for propulsion. If the Woodward Effect is not observed at the sensitivity limit of the experiment, this will also be worth knowing.

Acknowledgements

The authors are grateful to Marc G. Millis and the NASA Breakthrough Propulsion Program for providing encouragement and funding for the present experiment. We thank James F. Woodward for providing the very high quality barium titanate capacitors used in the experiment, along with much useful advice.

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Published as: AIAA/ASME/SAE/ASEE 37th Joint Propulsion Conference, Salt Lake City, July 8, 2001, Paper # AIAA-2001-3359, "Measurement of Repulsive Vacuum Forces"

AIAA-2001-3359

MEASUREMENT OF REPULSIVE QUANTUM VACUUM FORCES

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ABSTRACT

Quantum electrodynamics predicts that empty space (the quantum vacuum) contains a large amount of energy that corresponds to the lowest energy state (energy >0) of the electromagnetic field. Surfaces in the vacuum can experience forces that arise from the disturbance in the vacuum energy. The presence of attractive “Casimir” forces between uncharged, parallel, metal plates has been accurately verified in the last several years. Theoretical calculations have suggested the presence of repulsive vacuum forces for certain geometrical configurations. Here we describe an experiment in progress that is designed to determine if repulsive vacuum forces exist. In the experiment we measure the force exerted on a 200 um diameter metallized sphere mounted on an Atomic Force Microscope (AFM) that is placed very close to an array of gold microcavities. Observing a repulsive force on the sphere would verify the existence of repulsive forces. The ability to create attractive and repulsive vacuum forces by means of the geometry of the surfaces may permit the construction of devices that use ubiquitous vacuum energy in ways that assist with the space travel mission of NASA.

INTRODUCTION

Understanding the nature of vacuum forces and vacuum energy and how to manipulate this energy to obtain desired forces is a prerequisite to using these ubiquitous natural resources in any space application[1]. The theory for vacuum forces and quantum vacuum energy comes from Quantum Electrodynamics (QED), the theory of the interaction of matter and light[2]. **The role of the quantum vacuum is pervasive in modern physics. For example, it is involved in the calculation of atomic energy levels, the magnetic moment of the electron, the mass of elementary particles, spontaneous emission, dispersion forces between molecules, the large-scale structure of space-time.** **The experiment discussed in this paper is part of a three-year effort to begin to build, step by step, the knowledge base necessary for vacuum engineering. Our objective is to develop theoretical models of elementary systems that utilized vacuum forces and energy, to understand how these models behave, and then to explore some of these models experimentally. Since the critical dimensions required for these devices are typically micron to submicron, the experimental research utilizes microfabrication technology, and the methods developed for MicroElectro-Mechanical Systems (MEMS).**

In space applications the application of vacuum energy systems might be power generation, propulsion itself, or the manipulation of the metric of space-time itself by the creation of regions of positive and negative energy density[3]. It is too early to determine if such developments are possible or to be able to clearly determine the role of vacuum energy in future space applications. If we can develop technologies for space travel that utilize vacuum energy, it is very convenient since this energy is pervasive throughout the universe.

Fifty years ago, Casimir predicted that the modifications to the vacuum energy arising from the presence of two uncharged, parallel, metal plates would cause the plates to attract each other. This attractive Casimir force varies as the inverse fourth power of the separation. At a separation of 10 nm the force/area is about 1 atm. In 1997 the prediction of Casimir was verified for the first time. In 1998 precision measurements corroborated the predictions of an attractive vacuum force between neutral parallel plates to an accuracy of several percent. **In March 2001, scientists at Lucent Technology used attractive parallel plate vacuum forces (Casimir forces) to actuate a MEMS torsion device[4]. Other MEMS devices using vacuum energy have been proposed. [5]**

Recent calculations have indicated that forces due to the quantum vacuum predicted by QED depend very strongly on the geometry of surfaces. For certain rectangular metal cavities, QED predicts the existence of repulsive forces on the walls of the cavity[6]. **In this paper we describe the current status of the first experiment specifically designed to measure repulsive forces due to modifications in vacuum energy density achieved by using metal surfaces.** The vacuum force is measured by means of an Atomic Force Microscope using a 200 um diameter metallized ball placed on the end of a calibrated cantilever. Our model suggests that a repulsive force on the ball would be observed when it approaches within 10's of nanometers from the top of an array of rectangular cavities, each of which is 100nm across and 1 um deep, patterned in gold using x-ray photolithography (Figure 2). For small separations between the surface of the sphere and the top of the cavity array, we are approximating an array of closed cavities, which, according to a QED calculation, exhibit repulsive forces. **The force between the sphere and the cavity array is modeled numerically, with heuristic approximations, to be compared to the measured force. It is important to note that no rigorous method has yet been developed to calculate the vacuum force between any two non-planar conducting surfaces using QED.** Only the parallel plate problem has been solved. Indeed there is some disagreement that a repulsive Casimir force should ever be present between two separate bodies[7]. Measurement of repulsive forces between separate conducting bodies may be expected to stimulate new developments in QED.

If our experiment verifies the existence of repulsive vacuum forces, then it may be possible to utilize repulsive forces as well as attractive vacuum forces in microelectro-mechanical systems (MEMS). The existence of attractive and repulsive Casimir forces might permit the development of a variety of novel MEMS devices of potential use to NASA.

Quantum Electrodynamics (QED), Vacuum Energy and Casimir Forces

Quantum Electrodynamics (QED), the theory of the interaction of electromagnetic fields and matter, has made predictions of atomic energy levels and electron magnetic moments that have been verified to 1 part in 10^{12}, which makes QED the most precisely verified theory in science[8,9]. In order to achieve this accuracy, QED predictions have to include the interaction of matter with "empty space" or, more accurately, the quantum vacuum[10].

Some predictions of QED are less enthusiastically received by the physics community than others. One of the confounding predictions of QED is an energy density in empty space that is many orders of magnitude greater that the energy density of matter itself[11]. For years this feature of QED was dismissed as of no physical significance. However, observable forces can result when surfaces are present that alter this vacuum energy density. About 50 years ago, Phillips Laboratory physicist H.G.B. Casimir predicted the presence of an attractive quantum vacuum force between neutral, parallel, metal plates[12]. In the last three years, experiments have accurately confirmed this prediction of QED for the first time, verifying the existence of attractive vacuum forces between conductive surfaces[13,14,4]. The parallel plate Casimir force goes as the inverse fourth power of the separation between the plates. At a separation of 100 nm the predicted force/area is equivalent to about 10^{-4} atm.; at 10 nm it is about 1 atm.

BACKGROUND

Since most aerospace researchers do not have backgrounds in quantum systems, we provide a brief background to motivate our study. It is certainly not obvious that there should be any energy at all in empty space, much less a very large amount! Nor is obvious why there should be forces due to the vacuum fluctuations. The evidence for this theoretical conclusion lies in numerous well verified experiments on atomic energy levels, the magnetic moment of the electron, the behavior of liquid helium, and the scattering of elementary particles[15].

Vacuum energy is a consequence of the quantum nature of the electromagnetic field, which is composed of photons. A photon of frequency ω has energy $\hbar\omega$, where $\hbar$ is Planck's constant. **The quantum vacuum can be interpreted as the lowest energy state (or ground state) of the electromagnetic (EM) field that occurs when all charges and currents have been removed, and the temperature has been reduced to absolute zero. In this state no ordinary photons are present. Nevertheless, because the electromagnetic field is a quantum system, like an atom, which has internal motion even at absolute zero, the energy of the ground state of the EM field is NOT zero.** Although the average value of the electric field <E> vanishes in the ground state, the Root Mean Square

(RMS) of the field <E^2 > is **not** zero. Similarly the RMS of the ground state magnetic field <B^2> is not zero. Therefore the electromagnetic energy in the ground state, which from classical electrodynamics is proportional to <E^2> + <B^2>, is not zero. **A detailed theoretical calculation tells us that the electromagnetic energy in each mode of oscillation with frequency _ is ½○_, which equals one half of the amount of energy that would be present if a single "real" photon of that mode were present.** Adding up ½○_ for all possible modes of the electromagnetic field gives a very large number for the vacuum energy E_0 in the quantum vacuum:

$$E_o = \frac{1}{2}\sum_i \hbar\omega_i \qquad (0.1)$$

The resulting vacuum energy E_0 is infinity unless a high frequency limit is used.

Inserting surfaces into the vacuum causes the modes of the EM field to change. This change in the modes that are present occurs since the electromagnetic field must meet the appropriate boundary conditions at each surface[16]. **Surfaces alter the modes of oscillation and therefore the surfaces alter the energy density corresponding to the lowest state of the EM field.** In actual practice, the modes with frequencies above the plasma frequency do not appear to be significantly affected by the metal surfaces since the metal becomes transparent to radiation above this frequency. In order to avoid dealing with infinite quantities, the usual approach is to compute the finite change in the energy of the vacuum λ_0 due to the presence of the surfaces[17]:

$$\Delta E_0\left[\begin{matrix} change \cdot in \cdot vacuum \cdot \\ energy \cdot due \cdot to \cdot sufaces \end{matrix}\right] = E_0\left[\begin{matrix} energy \cdot in \cdot \\ empty \cdot space \end{matrix}\right] - E_S\left[\begin{matrix} energy \cdot in \cdot space \cdot \\ with \cdot surfaces \end{matrix}\right] \qquad (0.2)$$

where the definition of each term is given in brackets. This equation can be expressed as a sum over the corresponding modes:

$$\Delta E_0(due \cdot to \cdot sufaces) = \frac{1}{2}\sum_{n}^{\substack{empty\\space}} \hbar\omega_n - \frac{1}{2}\sum_{i}^{\substack{surfaces\\present}} \hbar\omega'_i \qquad (0.3)$$

The quantity ΔE_0, which is the change in the vacuum energy due to the presence of the surfaces, can be computed for various geometries. The forces F due to the quantum vacuum are obtained by computing the change in the vacuum energy for a small change in the geometry. For example, consider a hollow conducting rectangular cavity with sides a_1, a_2, a_3. Let en(a_1, a_2, a_3) be the change in the vacuum energy due to the cavity, then the force F_1 on the side perpendicular to a_1 is:

$$F_1 = -\frac{\partial en}{\partial a_1} \qquad (0.4)$$

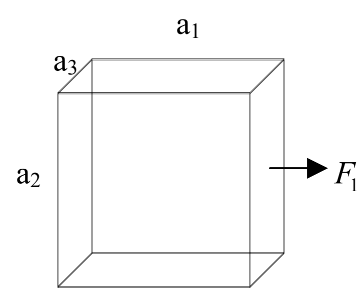


Figure 1. Geometry of rectangular cavity.

Equation (0.4) also represents the conservation of energy when the wall perpendicular to a_1 is moved infinitesimally[18]:

$$\delta en = -F_1 \delta a_1 \qquad (0.5)$$

Thus if we can calculate the vacuum energy as a function of the dimensions of the cavity we can compute derivatives which give the forces on the surfaces. For uncharged parallel plates with a large area A, very close to each other, this equation predicts an attractive or negative force between the plates:

$$F_{att} = -\frac{\pi^2}{240}\frac{\hbar c}{d^4} A \qquad (0.6)$$

This force is called the parallel plate Casimir force, which was measured in three different experiments in the last three years[13,14,4]. The

Casimir force has only been computed and measured for this very large parallel plate geometry.

QED makes some unexpected predictions about Casimir forces in other geometries that have never been verified. For conductive rectangular cavities, the vacuum forces on a given face can be repulsive (positive), attractive (negative), or zero depending on the ratio of the sides[6]. **We are particularly interested in measuring these repulsive Casimir forces. Verifying the existence of such forces would have important implications in quantum electrodynamics and would be an important step to utilizing Casimir forces in a variety of MEMS devices.**

DESCRIPTION OF THE EXPERIMENT

Atomic Force Microscope

It is not practical to directly measure the force on one wall of a submicron metallic cavity. Hence another approach is needed. We chose to use an Atomic Force Microscope (AFM), which can provide a very sensitive measure of forces into the piconewton range (10^{-12} Newton). The AFM employs a 300 um long micromachined silicon nitride cantilever with a 200 um metallized sphere on the end that can be used to probe the vacuum energy density in the neighborhood of a rectangular micromachined cavity with no top surface[19] (Figure 2). When the sphere experiences a force, the cantilever is deflected. The deflection of the sphere is measured by shining a laser diode onto the reflective surface of the cantilever. The reflected light is collected in a photodiode that is divided into two adjacent regions. As the spot of light moves during a deflection, the ratio of current from the two regions changes, giving a sensitive quantitative measure of the cantilever deflection. It is possible to measure deflections of several nanometers in this manner. The cantilever is calibrated by determining the cantilever deflection for a known electrostatic force. The high precision of this experiment is made possible by the use of a Molecular Imaging AFM system that was specially developed at the University of Alabama at Huntsville for vacuum operation. With the very small distance (much less than the mean free path of the molecules) between the sphere and cavity, gas molecules can become effectively trapped, taking hours to remove under vacuum. For the most reliable measurements it is necessary to remove the trapped molecules and operate at a sufficiently low vacuum. Trapped molecules may result in a squeeze film damping force because the cantilever is always vibrating slightly.

The AFM stage was connected to a vacuum flange with the necessary feedthroughs. The sample is mounted and aligned when the AFM is in air (Figure 3a). Then the AFM is inserted into the vacuum chamber and the flange bolted in place using copper gaskets (Figure 3b). The vacuum without the AFM is 10^{-8} torr; inserting the AFM reduces the vacuum to about 10^{-4} torr. The system is pumped with a turbo molecular pump and an ion pump. The AFM is housed in a clean room environment.

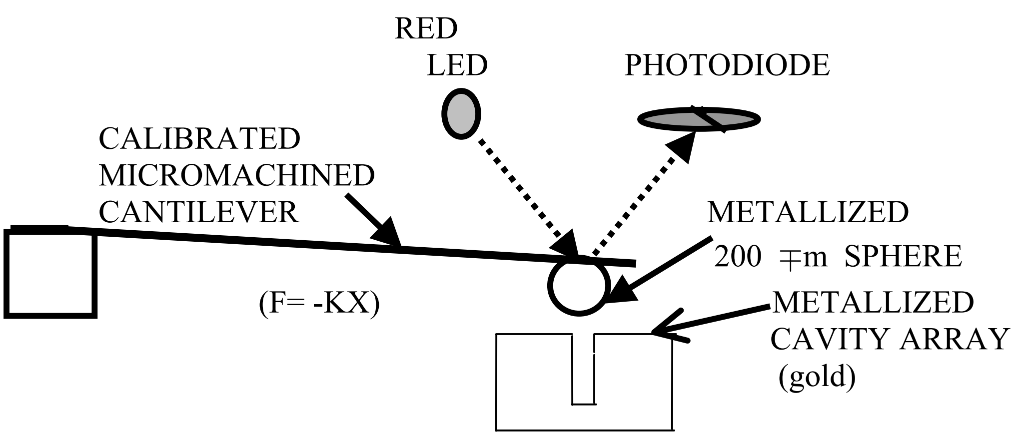
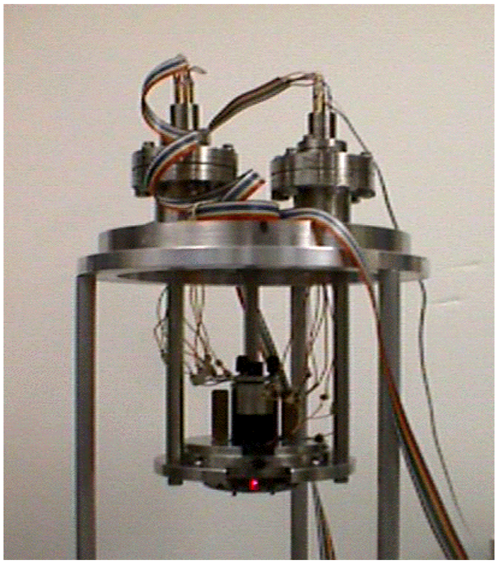


Figure 2. Schematic of Atomic Force Microscope measurement of the vacuum force between a metallized sphere on a cantilever and a rectangular cavity etched in gold (not to scale).

The force constant of the AFM cantilever is measured by using electrostatic forces. A know potential is applied between the test surface and the cantilever, and the deflection of the cantilever due to this potential is measured. The corresponding force is calculated using a finite element classical electrodynamic calculation. The system was tested by making measurements on the attractive Casimir force between the metallized sphere and a flat gold region and comparing these results to know values.



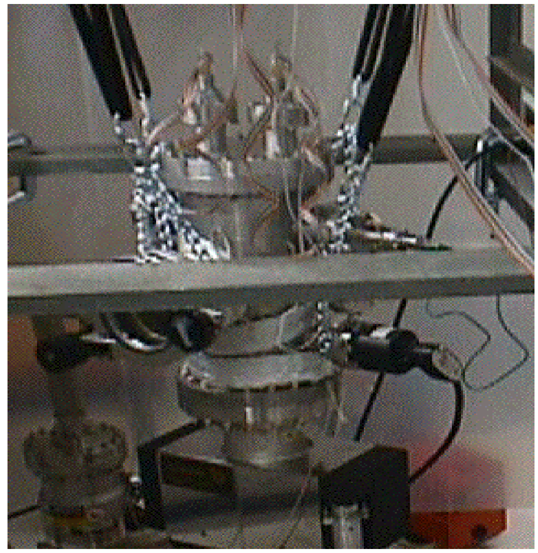


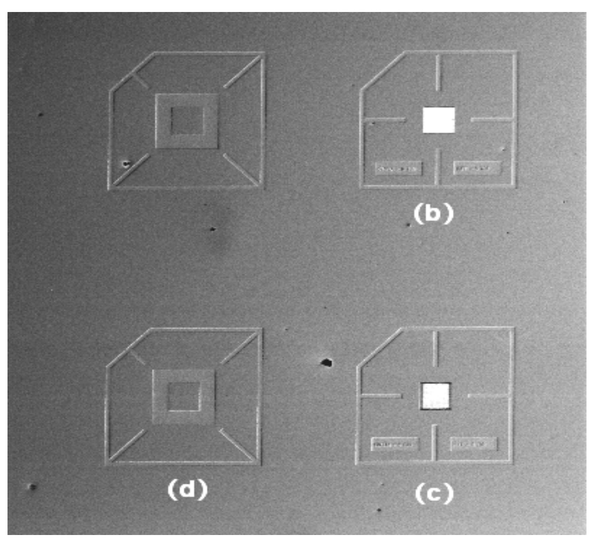
Figure 3. (a) shows the AFM stage below the vacuum flange, connected to the vacuum feedthroughs above. (b) shows the AFM mounted inside a small, stainless steel, vacuum chamber supported by elastic cords to reduce vibration.

Cavity Design

Numerical computations were done of the change in the vacuum energy and vacuum forces for a variety of rectangular cavities using QED methods[1,6]. The goal was to determine a cavity geometry that 1) would yield a large, detectable, repulsive force, 2) the repulsive force would change slowly with distance, and 3) that could be fabricated. The second requirement was deemed advisable to insure that the repulsive vacuum force would not vary too rapidly as the distance between the sphere and the opening of an etched rectangular cavity changed. The final cavity design selected was 0.1 um x 100 um x 1 um (width x length x depth), with walls that are 0.1 um thick.

Wisconsin Center for X-Ray Lithography. The cavity arrays fabricated are 100um x 100 um square, with cavity walls 0.5 um deep, with thickness t between 250 and 300 nm thick, and cavity widths w between 125 and 150 nm. Calibration surfaces for the AFM were also included in the design. The overall test pattern design is shown in Figure 4, and a portion of one of the cavity arrays closest to the target design is show in Figure 5.

Figure 4. A SEM photograph of a portion of the test die, showing two 500 um square calibration patterns on the left, and two 500 um square cavity array regions on the right side. The center of each calibration pattern is a flat gold surface at the same level as the bottom of the cavities, surrounded by a gold surface at the level of the top of the array. The white regions on the right are the 100 x 100 um cavity arrays. The rectangular regions below the arrays indicate the nominal cavity width and wall thickness (50 x).



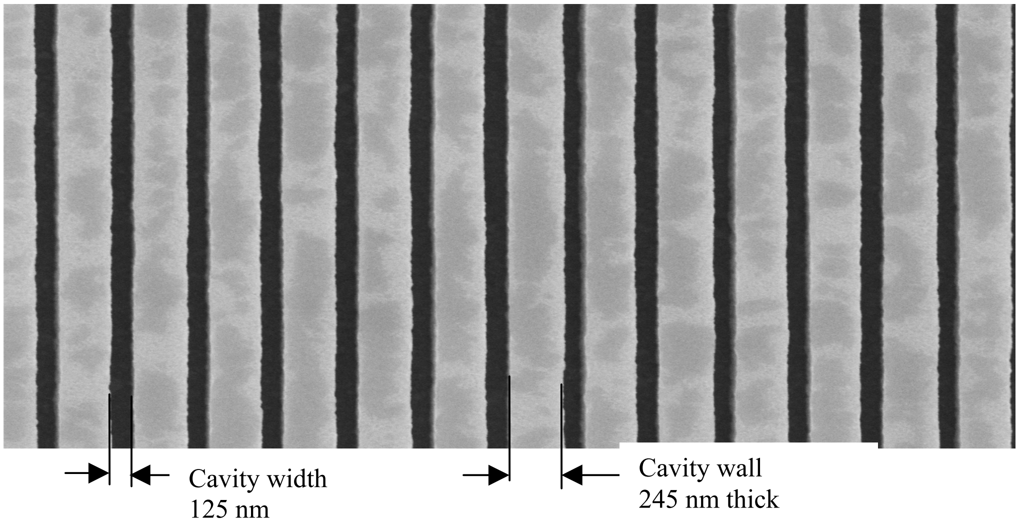


Figure 5. SEM photograph of portion of the gold cavity array. Each cavity is actually100 um long. The entire array is 100 um wide (magnification 37,000; 15kV).

Theoretical Modeling

As mentioned previously, no QED method has been developed to compute the vacuum forces between separate conducting surfaces. There is no theoretical model for such a configuration of two separate surfaces in the literature; no QED calculation of Casimir forces have been done except for planar or slightly rough planar surfaces. Hence we developed a heuristic model in which we assume the force on the sphere arises from two effects: 1) the attractive force due to the proximity of the sphere to the flat top surfaces of the cavity walls (parallel plate attractive Casimir force Eq 1.6), and 2) the repulsive forces on the sphere due to the cavity. The geometry of the experiment is shown in Figure 4.

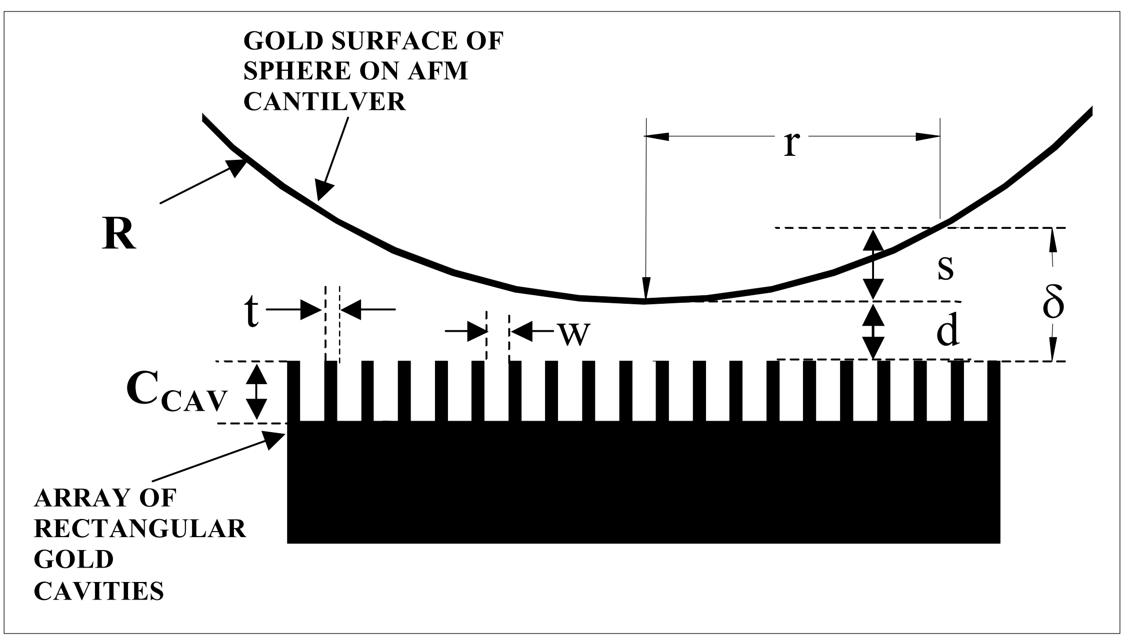


Figure 6. Distance definitions, illustrating actual cavity depth (C_{CAV}), individual cavity width (w), cavity wall thickness (t), separation distance (*d*), local sag (*s*), and local separation distance (δ).

The sphere has radius *R*. The closest point or tangent point of the sphere is located a distance *d* above the tops of the cavities. The local separation distance is $\delta = d + s$, where *s* is the local sag of the spherical surface. The quantity δ can be given as a function of r, the horizontal distance from the tangent point of the sphere. The expression for the attractive Casimir force Eq. 0.6 is actually derived for an infinite parallel plate geometry in which the lateral dimensions of the plates are much bigger than the spacing between the plates. Since this condition is not met for spacing d>t (width of cavity wall), we applied a correction factor to the attractive force, obtaining the expression for the attractive force:

$$F_{att}(r) = \frac{\pi^2}{240}\frac{\hbar c}{\delta(r)^4} A_w \left(\frac{t}{t+\delta(r)}\right) \qquad 0.7$$

where we used the local separation distance $\delta(r)$, t is the thickness of the cavity wall, and A_w is the area of the tops of the cavity walls. The QED calculation of the repulsive Casimir force was for a closed, rectangular metallic box. Therefore we need a method to correct for the experimental geometry in which there is a gap at the top of the box. For the repulsive cavity force, we used the computed force for a closed cavity of width "w" with a depth equal to the actual depth (C_{CAV}), and multiplied it by an approximate correction factor K(r) suggested by theoretical analysis[20]:

$$K(r) = \left(\frac{C_{CAV}}{C_{CAV} + \delta(r)}\right)^3 \left(\frac{w}{w+\delta(r)}\right) \qquad 0.8$$

Eqs. 0.7 and 0.8 predict that both forces decay rapidly as the separation distance is increased. Rather than sum over individual cavities, we used an effective pressure distribution, which is an area-weighted combination of the cavity force and wall force. This provides a pressure distribution *p*(*r*) over the surface of the sphere, where *r* is the radial coordinate. This pressure distribution depends on the geometry, including the separation distance, *d*.

To obtain the total force on the sphere, we integrated the pressure *p(r)* on the bottom of the sphere due to the sum of the forces, i.e.,

$$F = \int_0^{R/2} 2\pi r p(r) dr \qquad 0.9$$

Figure 7 shows a plot of the force F as a function of the separation d for a cavity array with 1) the target dimensions, namely w= 0.1 um wide with t=0.1 um thick sidewalls and 1.0 um deep, and 2) the best actual cavity dimensions fabricated, namely w=0.125 um wide cavities with t=0.250 um sidewalls, 0.5 um deep.

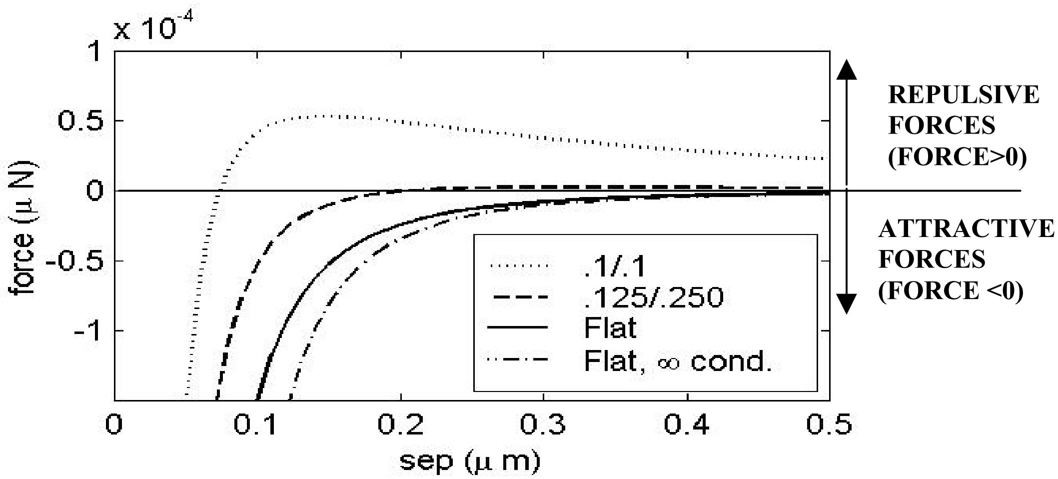


Figure 7. Force vs. distance d for a 100 um square cavity array with 1) the target dimensions, cavity width w = 0.1 um, wall thickness t=0.1 um, depth Ccav = 1.0 um deep; 2) the best fabricated cavity, width w=0.125 um, thickness 0.250, depth 0.5 um deep. The two uppermost curves show the force for the sphere above the cavity arrays. The solid curve shows the attractive force for a flat surface, with no cavities. Conductivity corrections are included. The sphere diameter is 210 um.

Also shown for comparison, is the calculated force (labeled Flat in the figure) for the case of a sphere over a flat surface, i.e. with no cavities at all in the gold. The known correction factors for finite conductivity for the force between parallel plates were used except for the curve labeled infinite conductivity. For the lack of any other theory, the same conductivity correction factors were applied to the cavity geometry.

For the parallel plate case, the force is always negative or attractive, and the force decreases rapidly (Eq 1.7 integrated over the hemisphere, or approximately as $-1/\delta^4$) with the separation δ. The component with upward curvature in the cavity array curve is due to the repulsive force (Eq 1.8 integrated over the hemisphere, which goes approximately as $1/\delta^3$). Because of the more rapid inverse variation of the attractive force, the attractive force dominates at very small separations d, going to zero more rapidly than the attractive force. Hence the repulsive force dominates at larger separations, above about 0.1 um. From QED we expect that smaller cavities would give larger repulsive forces; and thinner walls give smaller attractive forces. The predictions of the model show this desired behavior, and the model calculations appear to go smoothly into these known curves for flat surfaces. It appears that the repulsive force is on the edge of detectability for the cavities fabricated.

CONCLUSIONS

Quantum electrodynamics, which has made predictions which have been verified to 1 part in 10^{12}, predicts the existence of a large, ubiquitous, zero-point vacuum energy density in empty space. The question arises: Can we make use of this energy in some way to facilitate space travel, such as energy generation, propulsion, or creation of wormholes? It is too early to determine if such developments are possible or to be able to clearly determine the role of vacuum energy in future space applications. Our investigation begins with what we do know about vacuum energy, and extends those boundaries. We know that QED predicts that as a consequence of this energy, an attractive force will exist between uncharged, parallel, metal plates. In the last few years, accurate measurements have confirmed the existence of this force. QED also predicts the existence of repulsive forces in small rectangular metal boxes in which one dimension is much less than at least one of the other two dimensions. Although no one has done a rigorous calculation, it appears probable, based on theory, that a repulsive force should exist between two separate surfaces that closely approximate such a closed box. Vacuum forces that are repulsive because of the geometry have never been observed.

We have designed an experiment to measure repulsive vacuum forces. A model has been developed to predict the vacuum force on a metallized sphere attached to a cantilever on an AFM when the sphere is brought to within nanometer distances of an array of gold cavities. An AFM that operates in vacuum at 10^{-4} torr has been constructed to perform the experiment. Based on our model calculations, it appears we should be able to measure repulsive vacuum forces using the AFM, provided the cavities have small enough dimensions. Based on our model calculations (Figure 7) the cavities fabricated to date (125 nm width, 245 nm wall thickness) have dimensions that may be too large to provide a clear indication of a repulsive force. We need to utilize cavities with dimensions of approximately 100 nm width, 100 nm wall thickness in order to have a clear indication of repulsive forces. The University of Wisconsin Center for NanoTechnology is currently upgrading one of its synchrotron exposure systems in order to provide features of this size.

If we can obtain repulsive as well as attractive vacuum forces by a suitable choice of geometry, we are one step closer to being able to design a variety of novel MEMS devices using vacuum energy that could assist in attaining some of the NASA objectives for space travel.

Acknowledgements: GJM would like to thank Marc Millis and the NASA Breakthrough Propulsion Physics Program, MEMS Optical Inc., and Quantum Fields LLC for their support of this program, and Robert Forward, Peter Milonni, Carlos Villarreal, Gabriel Barton, and Michael Serry for helpful conversations. MG and LS would like to thank Molecular Imaging Inc. for their support of the development of a vacuum AFM. We would like to thank Hui Liu for taking SEM photographs and Jeff Meier for assistance with microfabrication.

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AIAA-2001-3906

SEARCH FOR EFFECTS OF ELECTRIC POTENTIALS ON CHARGED PARTICLE CLOCKS

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ABSTRACT

Results of experiment to confirm a theory that links classical electromagnetism with the geometry of space-time will be described. The theory, based on the introduction of a Torsion tensor into Einstein's equations and following the approach of E. Schrödinger, predicts effects on clocks attached to charged particles, subject to intense electric fields, analogous to the effects on clocks in a gravitational field. We show that in order to interpret this theory, one must re-interpret all clock changes – both gravitational and electromagnetic – as arising from changes in potential energy and not merely potential. The clock is provided naturally by proton spins in hydrogen atoms subject to Nuclear Magnetic Resonance trials. No frequency change of clocks was observed to a resolution of 6 x10^{-9}. A new "Clock Principle" was postulated to explain the null result. There are two possible implications of the experiments: (a) The Clock Principle is invalid and, in fact, no metric theory incorporating electromagnetism is possible; (b) The Clock Principle is valid and it follows that negative rest mass cannot exist.

INTRODUCTION

The goal of the present work is to investigate an electromagnetic alternative to exotic physics for the purpose of coupling matter to space-time. Electromagnetic forces have distinct advantages. They are 10^{40} times stronger than gravity. They can be manipulated at will. Resources to create intense fields of virtually any geometry are readily available. However, there is currently no accepted theory linking electrodynamics directly with the geometry of space-time other than to curve it via extremely high energy densities. The mainstream approach taken is "bottom up", attempting to unite all forces in the context of quantum gauge field theory which has to-date been successful in unifying the weak and electromagnetic forces and describing the strong force in what is known as "the standard model". Gravity and therefore space-time geometry remains isolated from the internal geometry of gauge theory. If such a theory could be found and even its simplest predictions tested and verified, then there would be hope that electromagnetic coupling to space and time might be possible. This could lead to new interpretations and possibly new effects in gravitation and electromagnetism.

The experiments described in this work measure the predictions of a theory[1], linking space-time geometry and electrodynamics. This is grounded upon E. Schrödinger's later works on gravitation theory[2]. In his work, Schrödinger attempted to link electromagnetism to geometry through a non-symmetric affine connection (Torsion tensor). He failed at the attempt, primarily because of an error of oversight. The theory upon which the present work is based corrects this error[3], resulting in the definition of a new type of affine connection – an electrodynamic connection – that precisely matches Schrödinger's concepts.

THEORY

We describe a simplified theory and shall only write the new field equations and their solutions for the present case. The theory is summarized in the BPP final report*. The governing equations are:

$$G_{\mu\nu} = -\frac{\kappa}{2} u^{\sigma} (F_{\nu\sigma;\mu} + F_{\mu\sigma;\nu}) \tag{1}$$

$$F^{\mu\tau}_{\ ;\tau} = 0 \quad ; \quad F_{\mu\nu;\sigma} + F_{\nu\sigma;\mu} + F_{\sigma\mu;\nu} = 0 \tag{2}$$

$G_{\mu\nu}$ is the Einstein tensor. $F_{\mu\nu}$ is the Maxwell electromagnetic field tensor. u^{λ} is the test particle 4-velocity and κ = -e/mc2, the charge/mass ratio of the test particle. Greek indices range from 0, the time index, to 1,2,3, the space indices. Equation (1) is the modified Einstein equation including Electrodynamic Torsion. Equations (2) are the usual covariant Maxwell equations. Selecting a metric for an appropriate

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geometry results in a set of solvable differential equations coupling the metric and electromagnetic field variables.

Ideal Experiment

The theory predicts that a particle of charge e, and mass m, immersed in a suitable electric field but unshielded and supported will see, in its rest frame, a time differing from the proper time of an external observer arising from the electrostatic potential at its location. In general, from the theory, the time shift in a clock interval is related to the potential difference between two points:

$$\frac{d\tau_2}{d\tau_1} = 1 + 2\kappa(\varphi_2 - \varphi_1) \tag{3}$$

This equation is exactly analogous to that for the gravitational red shift.

One possible clock for such a test is Nuclear Magnetic Resonance. A proton placed in an intense electric field within a radio-frequency transverse field "H_1" coil aligned orthogonally to a uniform magnetic field, H_0, is resonant at the Larmor frequency, $\omega = \gamma H_0$, where the gyromagnetic ratio, γ, for the proton spin is proportional to e/m. We thus have a natural clock. From eq. (3) we expect the proton's clock frequency to depend on its relative positions r_1 and r_2:

$$\omega(r_2) = \omega(r_1)\left[1 + 2\kappa(\varphi_2 - \varphi_1)\right] \tag{4}$$

The Larmor field distribution is then given by

$$H(r_2) = H(r_1)\left[1 + 2\kappa(\varphi_2 - \varphi_1)\right] \tag{5}$$

From this it is straightforward to calculate the NMR lineshape and shift that will result when the electric field is turned on as compared to the field off. Under ideal circumstances, for a supported proton in a 8T magnetic field with a 5kV/cm electric field, a line shift and broadening of approximately five parts per million is expected. The expected NMR lines are modeled in the "Experiments" section.

Present Approach

In practice it is experimentally difficult to "support" a charged particle. Generally, this can be accomplished electromagnetically, but then, by definition, the electric field and force at the particle location must vanish since the charge does not accelerate. The approach we have chosen uses the proton in a hydrogen atom. It is supported electromagnetically. The consequences of this approach will be the main subject of the conclusions of this work. A detailed description of the three experiments performed follows.

EXPERIMENTS

Three experiments were performed: A temporally and spatially constant potential applied to the proton in the hydrogen atom; A time-varying but spatially constant potential applied to the proton in the hydrogen atom; A hydrogen atom physically displaced through an intense electric field.

Experiment 1 – Constant potential

A 354 MHz, 8.4 Tesla NMR system was chosen for the experiments. This magnet has a field homogeneity of 0.1 ppm or about 35 Hz, more than sufficient to resolve small effects. The proton sample was Benzene. The initial experiment was a simple free induction decay (FID) with the E-field on vs. off. The sample was enclosed in a 2mm thick aluminum can (Fig. 1) placed at high potential. Thus the E-field will vanish in the interior of the can at the sample but there will remain a constant potential. The voltage terminal (sample chamber) could be set + or – with respect to ground and the NMR FID was monitored.

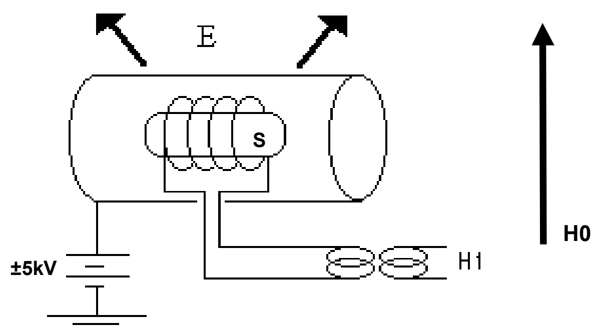

Figure 1. NMR "can" arrangement. External magnetic field, H0, is perpendicular to the radio frequency field, H1, applied through a coil wrapped around the proton sample, S. The 5kV electric field is applied outside the can leaving a constant 5kV potential inside.

A field homogeneity of 10 ppb was achieved for the 8.4T field, sufficient to resolve the smallest predicted effects. The observed line shift, was $\Delta\nu / \nu \leq 0 \pm 1.0\text{x}10^{-9}$, consistent with a null prediction of both classical E&M and the present theory. The null result is consistent with both classical theory and the present one.

Experiment 2 - Time-varying potential

The second experiment, a time-varying potential applied to the proton in the hydrogen atom, was initially expected to produce an effect. However, it was found during the course of this program that this theory was also invariant under a pure time-varying potential[5], a result consistent with the classical "Lorentz gauge condition" which is the relativistic generalization of the Coulomb gauge condition. That is, it states that the potential is also arbitrary to an additive time-derivative of a scalar. Thus, a null result was also expected and was observed. A "spin-echo" experiment was performed to observe any phase shift introduced by the time varying electric field. Extreme care was taken to calibrate the system to ensure that any small phase shift could be identified and that stray currents would not affect the data. Upon application of a 5KV step-function (20 ms risetime) between the aluminum can and ground in both turn-on and turn-off modes, the observed shift in the NMR line was $\Delta\nu/\nu \le 0 \pm 1.0\text{x}10^{-11}$.

Experiment 3 - Physical displacement of Hydrogen atom through high electric field

For the third and final experiment, hydrogen in benzene at room temperature was gravity-flowed between two electrodes, an upper one at ground potential and a lower one at +5000 V, both situated in the NMR coil in the external 8.4T magnetic field while NMR was performed with the electric field on and off. The electrodes were copper discs placed in the 3mm I.D. of glass tubing and connected to a high voltage source through glass/epoxy seals. The electrode spacing was 1.0 cm giving an average electric field of 5000V/cm. The 2-turn NMR coil diameter was 1.5 cm ensuring that the HV region was inside the coil. The coil was untuned to avoid radiation damping since the signal was already very large. Figure 2 shows the NMR coil system arrangement and a photo of the open chamber.

An NMR FID experiment was performed with and without flow. A 20-30 ms T_2 was obtained by careful adjustment of the B-field shim coils. The NMR line and effects of flow without the presence of an E-field were modeled. The T_2 value gives a line width of approximately 17 Hz ($\Delta f = 1/\pi T_2$). Figure 3 shows the measured NMR line with voltage off as a function of flow velocity through the coil varying from 3 cm/s to 50 cm/s. Since the FID has a time constant of 20-30 ms, the proton must stay in the H1 field at least this long in order to contribute a significant time-shift signal arising from the maximum 5kV potential change. This corresponds to a flow speed of 15-30 cm/s, the mid-range of the chosen flows. Note that the measured shift with zero volts is approximately 10 Hz, from 0 to 50 cm/s flow rate, in approximate agreement with the theoretical calculation, Figure 3. Figure 4 shows the predicted lines for a maximum potential of 5000 Volts. The shift is at least ten times that for zero volts.

For the flow experiment, the NMR line was obtained for voltage off, voltage on, and a dummy voltage on (voltage on but HV cable disconnected). The probe voltage was discharged when the dummy experiment was performed. Figure 5 shows data for flows of 0, 3, 6, 12, 25 and 50 cm/s with the voltage applied .

We note in Figure 5 that there is no change in the line positions greater than the FFT resolution of ± 2 Hz corresponding approximately to a line shift of $\Delta\nu/\nu \le 0 \pm 6.0\text{x}10^{-9}$, at least a hundred times smaller than the predicted shift of Figure 4. Figure 3 is therefore representative of the results with applied field as well.

When the experiment was completed, the probe was disassembled and carefully inspected to ensure that all voltage connections were secure.

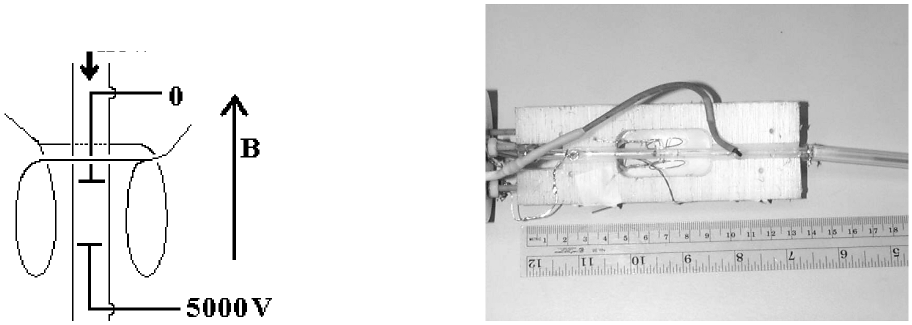

Figure 2. Diagram and photo of NMR coil and flow arrangement for E-field experiment

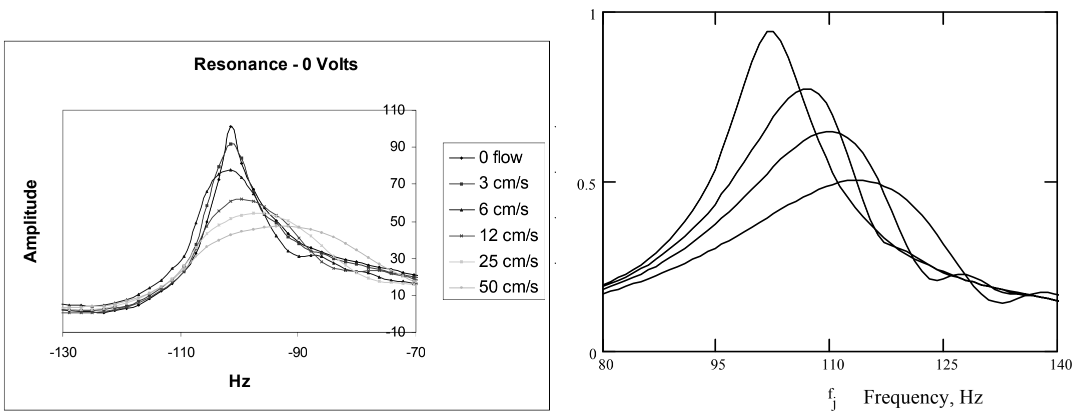

Figure 3. Measured NMR lines (left) and calculated (0,12,25,50 cm/s) for zero E-field and flows from 0 - 50 cm/s.

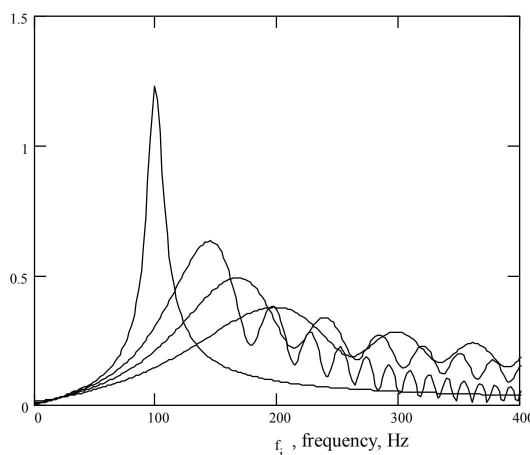

Figure 4. Calculated NMR lines for 5000V/cm E-field for flows of 0, 12, 25 and 50 cm/s.

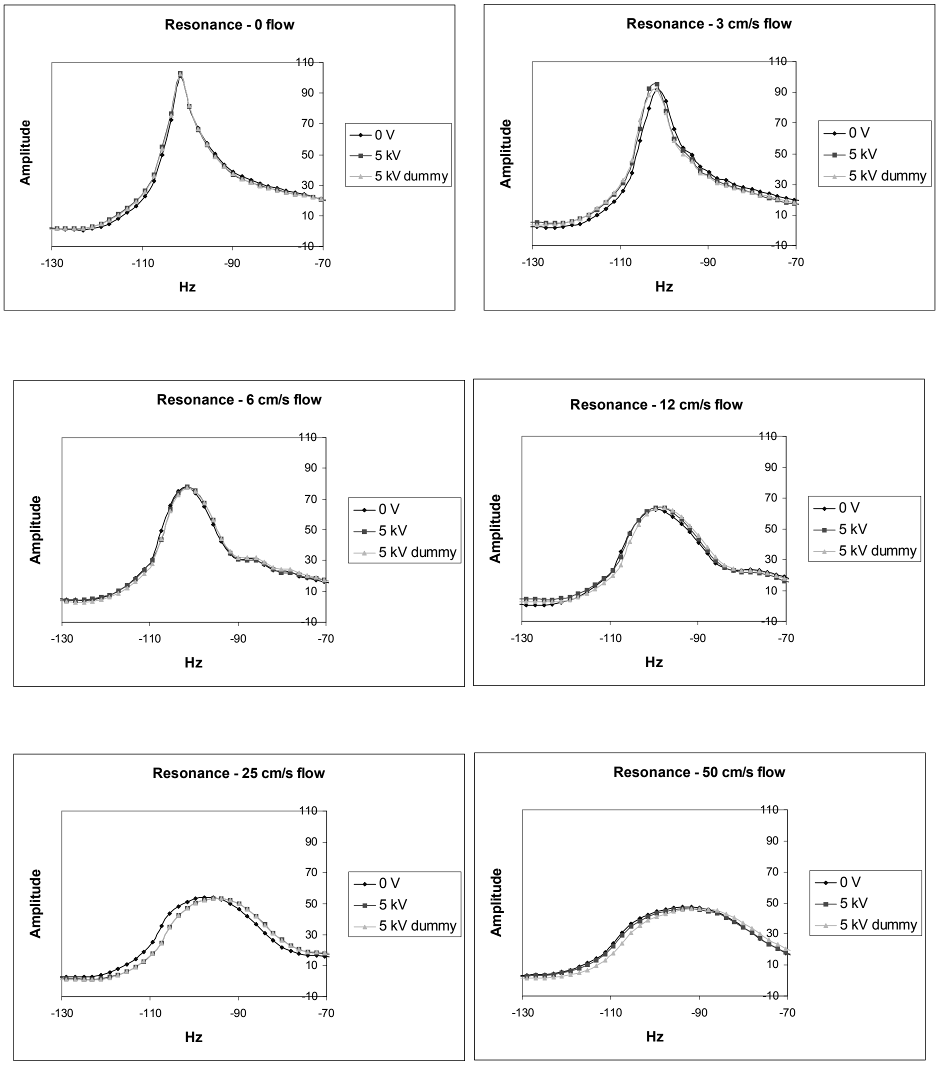

Figure 5. Measured variation in NMR line at 0, 6, 25 and 50 cm/s flow with applied voltage.

CONCLUSIONS

Experimental Conclusions

All three experiments showed null results. The first experiment, constant potential applied to the proton in the hydrogen atom, produced a null result as expected and explained earlier. The second experiment, a time-varying potential applied to the proton in the hydrogen atom, also produced a null result as expected and explained. From the second experiment we have learned that the present theory is relativistically Gauge Invariant in the context of Maxwell's equations – as it should be.

The third experiment, physical displacement of a proton in a hydrogen atom through an electric field, was expected to produce a frequency shift of 5ppm in the NMR line. No change was observed to high precision. This could be explained as follows. When a hydrogen atom is placed in an electric field, classically, only one effect is produced – an induced dipole moment of the atom resulting from the stretching of the electron orbital. Otherwise, no work is done on the hydrogen atom (except for the exceedingly small amount involved in stretching) since the work done on the proton is cancelled by the opposite work done on the electron(due to its negative charge) in the electric field. Furthermore, it is straightforward to show[4] that no work is actually done on the proton itself since the electric force on it is precisely balanced by an opposing force, in the field direction, from the electron.

Implied Conclusions

If we substitute potential energy change and therefore work done rather than simple potential in the metric, then the fact that no work is done on the proton because of the electron's influence can explain the null result. We now discuss the relation of work to the metric.

Relation of the Metric to the Lagrangian and Work Done

Let $\tilde{L}$ be defined as the specific Lagrangian or Lagrangian per unit rest energy,

$$\tilde{L} = \frac{(T-V)}{mc^2} \quad (6)$$

where T, V and m are the kinetic energy, potential energy and rest mass of the test particle respectively.

Suppose we are at rest at some height z in a gravitational field, so that $T=0$ and $V=mgz$, then $\tilde{L} = gz/c^2$. We have shown for weak fields and nonrelativistic speeds that the proper time element can be written in terms of the Specific Lagrangian and coordinate time element as:

$$d\tau = \sqrt{1-2\tilde{L}}\; dt \quad (7)$$

This describes the behavior of clocks. Consider two positions in the gravitational field z_1 and $z_2 = z_1 + h$. Assume a proper time interval $d\tau_1$ at z_1 and $d\tau_2$ at z_2. Then, for weak fields:

$$\frac{d\tau_2}{d\tau_1} = 1 - \frac{gh}{c^2} \quad (8)$$

We can rewrite this in terms of potential energy and Lagrangian rather than potential;

$$\frac{d\tau_2}{d\tau_1} = 1 - \frac{mgh}{mc^2} = 1 - (\tilde{L}_2 - \tilde{L}_1) = 1 - \Delta\tilde{L} \quad (9)$$

In general, a variation in the Specific Lagrangian results in a change in the clock rate. Referring more concisely to the metric for a single particle, *p,* we may express the Lagrangian change more clearly in terms of the net conservative work, W_c, done on *p.*

$$\Delta\tilde{L}_p = 1 - \frac{(\Delta T - \Delta V)}{m_p c^2} = \frac{\Delta T_p + W_c}{m_p c^2} \quad (10)$$

The weak-field, non-relativistic, metric for a given particle, p, acted upon by forces and hence net conservative work, W_{cp}, done upon it by all other particles in the field is given by

$$d\tau_p{}^2 = \left(1 - \frac{2W_{cp}}{mc^2}\right)c^2 dt_p{}^2 - dx_p{}^2 - dy_p{}^2 - dz_p{}^2, \quad (11)$$

We have rewritten the metric in this way because potential is not well-defined except through potential energy and work, where it is defined as work per unit mass in gravitation and work per unit charge in electromagnetism.

The Clock Principle

In the previous section we found a simple Lagrangian formulation that places gravitation on an equal footing with our theory in regards to changes in the temporal portion of the metric. The Lagrangian formulation deals with kinetic and potential energy changes. Clocks raised in a gravitational field are at rest in the two positions and can be slowly moved between them. Thus the Lagrangian becomes simply the negative change of potential energy(work done on) of the clock, moved from the lower position to the upper. However, we must be careful and can no longer use the word "clock" loosely. When we refer to "clock" henceforth, we mean the *mechanism of the clock*. Thus we mean that work is performed on the *mechanism*. Clearly all clock mechanisms are driven by energy changes. What is not as obvious is that the mechanism of any clock must reflect the proper time variations in a gravitational field. For example, the mass-spring mechanism of a simple clock must somehow change with different heights in a gravitational field. Similarly, a pendulum clock must exhibit changes in its mechanism. Even an atomic clock is subject to this consideration. This brings us to the ***first clock postulate***:

1) Every clock has a mechanism which must be held accountable for observed changes in its measurement of time.

We shall now examine the relationship between work and changes in clock time in a gravitational field. We use the notation "nc" to mean nonconservative and "c" for conservative forces.

Einstein Rocket -- Equivalence Principle for clock changes in a Gravitational Field

We shall employ the famous Einstein rocket "gedanken-experiment" to demonstrate our concepts. Consider a rocket lifting a mass, *m*, by a stiff wire in a gravitational field. Let us suppose that we adjust its thrust to precisely oppose the graviational pull on the mass. The rocket-mass system is now balanced and hovers, for example, at the surface of the earth. An arbitrarily small external force, $\vec{\varepsilon}$, may now raise the system to a height, *h*. This is shown in Figure 7. The force $\vec{\varepsilon}$ does no work on the system since it can be made arbitrarily small. However, upon rising a height h, due to the infinitesimal assistance of the guiding force, the rocket does work on the mass *m*. The potential energy of the mass is V_1 at the surface and V_2 at height *h*.

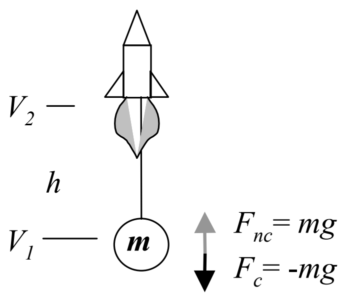

Figure 7. Balanced force configuration of a rocket-mass system

In this situation, the nonconservative force is that of the rocket. This is equal and opposite to gravity. We make the following definitions:

$$z_2 - z_1 = h \;;\; d\vec{s} = dz\hat{k} \;;\; \vec{g} = -g\hat{k} \qquad (12)$$

Then the non-conservative work performed on the mass m by the rocket is

$$W_{nc} = \int_{z_1}^{z_2} \vec{F}_{nc} \cdot d\vec{s} = mgh \qquad (13)$$

and the conservative work done on m by gravity, opposing the rocket is:

$$W_c = -mgh = -(V_2 - V_1) = -\Delta V \qquad (14)$$

Einstein rocket replaced by negative mass

Let us now reconsider the rocket of Figure 7. We can replace the rocket by negative mass equal in magnitude to the lower positive mass (Fig. 8). Earth's gravity repels negative mass and thus an amount *(-m)* will precisely balance the force of attraction on *m*, a situation equivalent to the rocket.

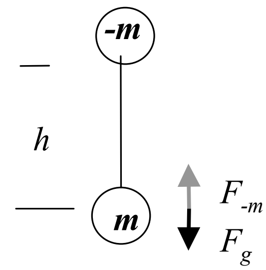

Figure 8. Balanced force configuration for rocket replaced by negative mass

We evaluate the work done in this situation. There are two forces acting on *m*, $\vec{F}_g$ and $\vec{F}_{-m}$. This time *both* forces are conservative. The total work done on the mass m is zero because there is no change in the kinetic energy, since $\vec{F}_{-m} = -\vec{F}_g$.

$$W_{total} = \int \vec{F}_g \cdot d\vec{s} + \int \vec{F}_{-m} \cdot d\vec{s} = \Delta T = 0 \qquad (15)$$

However, now the total work done on *m* is conservative since, unlike with the rocket, there are no non-conservative forces acting. The rigid wire transmits the conservative force from *–m*. Thus we find:

$$W_c = W_g + W_{-m} = 0 \qquad (16)$$

This model of a massive neutral dipole is exactly equivalent to an electric neutral dipole such as the proton and electron of a hydrogen atom in an electric field. In the latter case, the two forces acting on the proton, the external electric field and the opposing force of the electron are both conservative. The total conservative work on the proton is zero when the atom is moved a distance h through a known potential difference. That is precisely our experiment. There was no clock change observed.

This leads us to the ***second and third Clock Postulates***:

2) External conservative work done on a clock mechanism is responsible for changes in its rate when the motion of the clock can be neglected.

3) When the clock is not at rest, the change in its rate arises more generally from the change in the Specific Lagrangian for the mechanism.

The third postulate takes into account the change when there is kinetic energy present.

These postulates reconcile the observations and considerations of the present experiment with those observed for gravity. Therefore one should not expect to see a clock change in the imagined massive dipole experiment since there was no net conservative work done on m.

Inconsistency between General Relativity and existence of a neutral mass dipole

Now consider a clock on the mass *m* attached to the rocket. The mass *m* might itself be part of a clock mechanism. Upon reaching height *h*, the clock will change. But the mass *m* cannot distinguish between the pull of the rocket on the wire from that of the negative mass. In the case of the negative mass , the Clock Principle states that since no net conservative work is done on *m* , no clock change should be observed. So, there is a conflict here. It follows that:

Since we assume GR to be true, either the Clock Principle is false or a mass dipole cannot exist as the analogue of a charge dipole. Thus, if the clock principle is true, negative mass cannot exist. If the clock principle is false, then work and energy change are not related in general to time change. It follows that a metric theory of forces other than gravitation cannot be constructed.

Clock Conclusions

It is generally agreed that in order for a clock to indicate the passage of time, energy change in the mechanism is required. Thus, it appears that space is coupled to time through energy. When a clock is raised in a gravitational field, external work is performed on the mechanism. This permits a time change. If $W_c=0$ so that applied forces opposing conservative forces are also conservative, then there will be no observed clock change.

We have shown that if the clock principle is correct then ***negative mass cannot exist***. This does not preclude the existence of negative energy since the general energy-momentum relation has two roots,

$$E = \pm\sqrt{p^2c^2 + m^2c^4}$$

of which the positive root, in the rest frame of a particle of mass m (p=0), is the famous Einstein energy-mass relation.

ACKNOWLEDGEMENTS

This work was supported by the NASA Glenn Research Center under Contract NAS3-00094. We wish to thank Marc Millis for having the daring and fortitude to envision and create the BPP program and support this effort as part of it. We would like to thank Prof. Larry Mead for supportive discussions revolving around this new view of General Relativity. We also wish to thank Dan Leopold for his advice and support of the experiment.

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EXPLORATION OF ANOMALOUS GRAVITY EFFECTS BY MAGNETIZED HIGH-T_C SUPERCONDUCTING OXIDES

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ABSTRACT

Driven by the knowledge that mass-ejection from a rocket engine is a major drawback in the exploration of space, investigations of fringe effects (or abnormalities) in known science and dealing with mass reduction was undertaken. This research, then examines the possible connection between gravity and electro-magnetic affects on the Type II, YBCO superconductor, as reported by the Russian scientist, Eugene Podkletnov. It is suggested that the quantum fluctuations of the electrons across the multitude of superconductor grain boundaries in a properly prepared Type II; superconductors may produce a measurable force on the vacuum that could counteract the effect of gravity, an acceleratory force. Within known physicists, the driving phenomena appears to relate to both the Maxwell Stress Tensor as derived by Oliver Heaviside and Woodward's transient mass theory. As a means of improving this understanding, a simplified laboratory experiment has been constructed using a modified–automated commercial Cavendish balance. The larger lead masses used in this balance was replaced by a system to EM modulate a superconductor. Tests results were inconclusive because at both room temperature and at liquid nitrogen temperatures the application of the electromagnetic (EM) or rf energy resulted in an upward climb in the data.

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INTRODUCTION

Engineers working in the aerospace fields dealing with rocket engine technology quickly learn that mass-ejection is a major drawback in the exploration of space. Using current rocket technology a trip to the next star would easy consume the mass-energy equivalent of a planet in order to arrive within a reasonable lifetime with reasonable hardware and expendables for the journey. Technologies like nuclear fission and fusion offer some hope, but still will not support the "Star Trek" vision of space exploration. Therefore, the NASA Propulsion Research Center at the Marshall Space Flight Center in response to the propulsion challenges specified by the NASA Breakthrough Propulsion Physics (BPP)[**] project, specially to investigations fringe effects or abnormalities in known science and dealing with mass reduction, proposed to explore the recently report observation of anomalous gravitation behavior in experiments using high temperature superconductor.

The thesis of this research is to see if there is a possibility to circumvent the rocket equation without violating physical laws and to produce valid experimental data that can be used to show credible validation of these effects. The intend here is then to examining the possible connection between gravity and electro-magnetic affects on the Type II, YBCO superconductor, as reported by the Russian scientist, Eugene Podkletnov and provide a rigorous, independent, empirical conformation (or refutation) of the effect.

It has been suggested that the quantum fluctuations (or electromagnetic nature) of the electrons across the multitude of small

[**] Lead by the NASA Glen Research Center

superconductor grains, called Josephson junctions, in properly prepared sintered Type II, superconductors may produce a measurable force on the vacuum (i.e., space vacuum) that could counteract the acceleratory force of gravity.

The experiment that was proposed utilizes a commercially available torsion balance called a Cavendish balance, which is commonly used by physics students to measure the value of the gravitational constant. The extent of the experiment is not to measure the gravitational constant, but to measure the change in the dynamic angle induced on a torsion beam as a result of the attraction between the beam masses and external test masses (i.e., superconductor). In theory, the values of the calculated dynamic angles between two tests should be different if the masses are of different weight values. Assuming that the characteristics of the balance do not change between tests, the difference between the two dynamic angles can be used to correlate the mass change. Whereby, if a change is detected between a superconductor and an electro-magnetically radiated superconductor, one can deduce that there is a possibility that an interaction with the vacuum had occurred.

The research conducted here is but a first step in the possible application of a theory into an applicable engineering space drive model, which can then be used to design a purely massless propulsion system for interplanetary applications.

A successful or null test would however, not indicate the full benefit of the phenomena nor that it is truly a physical effect. Whereby, further testing would need to be conducted to validate the results and to devise the true nature and applicability to a space propulsion system.

BACKGROUND

A number of anomalous gravitational effects (or acceleratory forces) have been reported in the scientific literature during recent years, but there has been no independent confirmation with regard to any of these claims. One such experiments was reported by the Russian scientist, Eugene Podkletnov, in which he reported anomalous weight loss (0.05–2.1%) for a variety of test masses suspended above a rotating YBCO[#], type-II superconductor.[1,2] Further experiments using simplified apparatus without rotation have reported transients of up to 5% weight loss.[3,4] Still, a great deal of skepticism continues to be expressed, mainly due to uncertainties associated with experimental technique. Other researchers, for example, have yet to duplicate Podkletnov's rotating disk experiments and obtained null results in a set of simplified experiments using a stationary disk.[5]

The technical goal was then to critically test this revolutionary physical claim and provide a rigorous, independent, empirical confirmation (or refutation) of anomalous effects related to the manipulation of gravity by rf-pumped magnetized type-II superconductors. Because the current empirical evidence for gravity modification is anecdotal, our objective was to design, construct, and meticulously implement a discriminating experiment, which would put these observations on a more firm footing within the scientific community. Our approach is unique in that we advocate the construction of an extremely sensitive torsion balance with which to measure gravity modification effects by rf-pumped type-II superconductor test masses.

Three competing theoretical explanations have been proposed to explain these gravitational anomalies: (1) gravity shielding,[1,2] (2) absorption via coupling to a Bose condensate,[3,4] and (3) a gravito-magnetic force.[5-9, 18] To date, however, there has been no definitive corroboration between any of these theories and empirical observations. Therefore, it is clear that carefully designed and meticulously executed experiments are needed to explore these anomalies and to convincingly demonstrate the alleged effects. However, validation of a new theory is in itself a long and mischievous task. This is more so when you have to consider the nature of electrons at the atomic scale.

In light of the granular nature of a sintered YBCO superconductor disk, one can address the much larger grain interfaces in more macroscopic terms using electric-potentials, displacement currents, and magnetic fields. This is due to the Josephson junction effect at the interface, which is somewhat like an AC capacitor.

A search of the literature has produced several experiments using capacitors to interact with the vacuum to cause a force; 1) the Trouton and Noble (T-N) experiment[21], 2) the Biefield-Brown (B-B) experiment[10], 3) the Graham and Lahoz (Heaviside) experiment[20], and 4) the Woodward (Transient Mass) experiment[17].

ENGINEERING APPLICATION OF QUANTUM VACUUM

[#] Yttrium, Barium, Copper, and Oxygen.

As aerospace engineers we deal more with the technology development of machines that have proven to work within the physical boundaries of known physical laws, which govern the rocket equations. Speculative theories can only lead to misunderstanding and lost paths. Therefore, space propulsive systems are designed to overcome gravitational forces by the application of time varying the mass of a vehicle, i.e., the exhausting of onboard mass at high velocities. What seems to be lost in this rational is that as the propellant becomes smaller with higher and higher exhaust velocities, as in the case of a laser or photon drive, the mass approaches a more quantum state. The logical next step would then be to connect propulsion to the quantum vacuum through acceleratory forces, i.e., gravity.

Long ago internationally renowned physicists hypothesized that gravity is an induced effect associated with zero point fluctuations (ZPF) of the quantum vacuum.[13-14] Zeldovich first suggested that gravitational interactions could lead to a small disturbance in the non-zero quantum fluctuations of the vacuum and thus give rise to a finite value of Einstein's cosmological constant.[13] Sakharov later derived a value for Newton's gravitational constant G using frequency w as the only free parameter.[14]

$$G = c^5 / h \int w \, dw \tag{1}$$

where c is the speed of light and h is the Plank constant. The integral is carried out over all frequencies using the Plank frequency on observable electromagnetic phenomena (w_p ~ 10^{-33} cm) as a cutoff value.

Using this hypothesis as a basis, Puthoff has further extended Sakharov's condition in a relativistically consistent manner.[15] As a result of this work, it is possible to envision the attractive force of gravity in terms of the radiative interaction between oscillating charges. That is, the zero point field applied to subatomic particles. From this standpoint, it is plausible that MHz frequency irradiation of superconductors rich in Josephson junction sites, as occurred in Podkletnov's experiments, could lead to a gravity modification effect through quantum ZPF interaction.

Scientific evidence continues to mount in favor of a frequency dependent interpretation of gravity as an induced effect associated with the zero point fluctuations of the vacuum. Accelerating theoretical progress combined with the anomalous gravity modification effects observed in experiments with irradiated Type II superconductors leads one to strongly suspect a deep physical connection.

THE PODKLETNOV EXPERIMENTS

Podkletnov's gravity modification experiments were conducted in the early 1990's. Nevertheless, skepticism persists, especially since the experiments have not been adequately documented and repeated. Podkletnov reports the use of fairly large superconductor disks, 10 and 12 inches in diameter and approximately ½ inches thick, which were magnetically levitated and magnetically rotated in the presence of an rf electromagnetic field. Samples placed over the rotating disk initially demonstrated a weight loss of 0.2–0.5%. When the rotation speed was slowly reduced, the shielding effect became considerably higher and reached a maximum reduction of 1.9–2.1%.

Of what is known of the YBCO superconductor disk used in these experiments, it seems certain that a large number of superconductor-oxide Josephson junctions exist within the disk. These types of Josephson junctions, when conversed by an ac current, emit electromagnetic waves in the rf frequency range, and when radiated at rf frequencies, generate an ac current. In a general sense, Josephson junctions are very small capacitors with the electrodes composed of superconductor material and the dielectric composed of an oxide layer.[12] The junction is modeled as shown in figure 1, where the superconductors (SC) are small sintered grains (noting that one or both of the grains could be a normal conductor), rf is the rf energy applied, JJ is the Josephson junction site, and i is the induced or applied current.

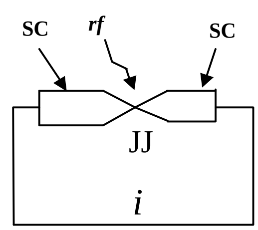


Figure 1. SC Josephson Junction Model.

A superconductor with a structure of sintered grains would have many flux pinning sites around which Josephson junction sites exist. Flux pinning is a well-known phenomenon associated with type-II superconductors (like YBCO) where magnetic flux penetrates the superconductor and is held in place by self-generated super-currents. Flux pinning results from any spatial inhomogeneity of the material, such as impurities, grain boundaries, voids, etc. where the magnetic flux can become trapped. To be most effective, these inhomogeneities must be on the scale of the order of the penetration depth or the coherence length, i.e. ~10.6 to 10.5 cm, rather than on the atomic scale where inhomogeneity causes electronic scattering which limits the mean free path.[12]

The Josephson junction sites at the grain boundaries would generally not produce flux pinning due to the resistive nature of the boundary. The exceptions might be under very high static magnetic field conditions. Radiation of the sites with rf energy would allow current flows, but could cause the flux to vibrate and jump from one site to another depending on the frequency.

Experiments conducted on both sintered and melt textured YBCO superconductors for the purpose of magnetic flux compression have shown that the rapidly moving flux with a millisecond rise time to approximately 1 kilogauss penetrates the superconductor with little (<35 gauss) compression of the field.[Ψ] This would indicate that a magnetic field could easily move through the body of a sintered superconductor to produce currents within the grain structure. Contradictory to this, it has also been shown during tests to repeat the Podkletnov experiment that an AC magnetic field will levitate a sintered (12 inch) disk.[++]

Podkletnov's experiment used both AC magnetic fields and rf energy. It would therefore seem that Podkletnov has produced a device to enhance the production of rf energy and rf energy to enhance the production of superconductor currents. These reinforcing phenomena should lead to high electron densities in the superconductor disk, focused at the Josephson junction sites and generated at the junction frequency.

It is then suggested here that the quantum fluctuations of the electrons across the multitude of Josephson junctions in properly prepared Type II, superconductors may produce a measurable force on the vacuum that could counteract the effect of gravity.

OTHER RELATED EXPERIMENTS

The capacitive like nature of the Josephson junction would make one wonder if other experiments have been conducted using capacitors to affect the vacuum. Research of the literature indicates that experiments using capacitors as a coupling mechanism to the quantum vacuum is not a new idea. In 1904, Trouton and Noble (T-N) reported that a mechanical force could be detected from a charged capacitor, which was free to rotate[21]. And in 1929, Townsend Brown reported translational motion using the now famous Biefield-Brown (B-B) effect, which utilizes capacitors with extremely high electrical potentials (>70 kV)[10]. To the author's knowledge, no one has report a successful duplication of the B-B experiment.[11] However in 1998, Cornille, Naudin, and Szames reported a successful duplication of the T-N experiment also using voltages near 70 kV.[22]

Ψ Conducted by the first two authors.

++ This work is being conducted under a NASA SBIR Phase II.

Trying to connect these two experiments to Podkletnov's experiment is somewhat deceptive as only statically charged capacitors with no magnetic fields were used. One could speculate that the leakage current across the dielectric medium could occur at some (low) frequency associate with the atomic electron energy states. Also, stray magnetic fields could have been present; at the least, the magnetic field of the earth was. From a more physical sense, the time varying magnetic fields in the Podkletnov experiment would have created time varying high electrical potentials in the superconductor.

In more recent times, Graham and Lahoz (in 1980) reported the use of a coaxial capacitor to produce rotational motion from the vacuum by setting up a non-vanishing Poynting vector, as Maxwell and Poynting foresaw and predicted by Heaviside's[**] time variation of Maxwell's equations.[20] Further, Woodward has recently done some very interesting work with capacitors, both theoretically and experimentally to validate the notion of a transient mass effect.[17] These two experiments do have similarity to the Josephson junction and a further clarification follows.

Heaviside Force

Oliver Heaviside in 1886 obtained an express from the divergence of the Maxwell stress tensor, which is a vector with units of force density (N/m^3), and therefore implies momentum transfer. Corum names this the Heaviside force f_H and gives it in vector form as

** Referred to as the Heaviside Force by Corum[19].

$$f_H = \frac{\partial (DxB)}{\partial t}, \qquad (2)$$

where D is the electric displacement and B is the magnetic induction[19].

Corum goes on to present a space-drive that was first presented in an essay by Joseph Slepian in 1949. In the essay, Slepian models the space-drive by employing an rf source to drive two solenoids and a parallel-plate capacitor electrically wired in series. The rf energy was directed between the plates and perpendicular to the electric field of the plates. In this arrangement, the current passing through the coils must also cross the capacitor. This is shown in figure 2.

In the Slepian model, one may say that the current can only cross the capacitor in the presence of an rf field. This is the case for a superconductor Josephson junction. In fact, Slepian space-drive model is a crude approximation of a Josephson junction and is only a short stretch to the junction model of figure 1.

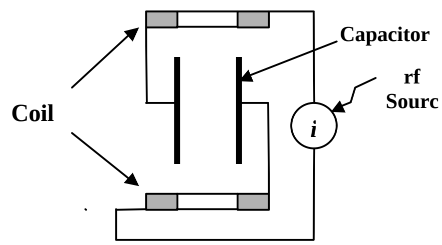


Figure 2. Slepian Space Drive Model.

Transient Mass Shifts

Woodward has come up with an equation for a transient mass shift (TMS) derived from Mach's Principle (Woodward, 1991). Woodward presented the transient mass shift ∂m_0 in general terms as:

$$\partial m_0 = \frac{bwP_0}{2pG r_0 c^2}, \qquad (3)$$

where ∂m_0 is the transient mass; b is the ratio f/c^2 (f is the gravitational potential due to all the matter of the universe) and is approximately 1 and unitless; w is the frequency of the driving voltage into the capacitors in radians per second; P_0 is the power applied to the capacitors in Watts; G is the gravitational constant = 6.673 x 10-11 N m2/kg2; r_0 is the density of the capacitors; and c is the velocity of light = 2.9979 x 108 m/s.

A connection between Woodward's transient mass and Podkletnov's gravity modification experiment was presented in a previous paper.[16] In the paper, a model of the Josephson junction, transient mass relationship was given similar to figure 3.

As with figure 1, figure 3 presents a two-grain Josephson junction where one grain is a normal conductor NC and the other is superconductive SC. The current has been represented as a function $f(i)$ due to the uncertainty of this mechanism (i.e., time varying fields and rotation). The prospective is that electron charges e formed in the normal conductor. The application of the rf energy at the appropriate frequency allows the flow of electron to cross the junction as pairs $2e$. Noting the reverse effect is also possible.

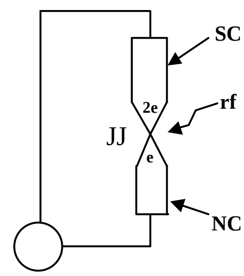


Figure 3. Josephson Junction TMS Model.

As cited in the previous paper, Woodward's TMS formula has commonality with Modanese's anomalous coupling theory (ACT)[3,4] and Woodward's capacitor experiment has commonality with the layered superconductor disk of Podkletnov's second experiment where the top part was a superconductor and the bottom portion a normal conductor. The TMS formula derives a mass fluctuation from a time-varying energy density. The ACT suggests that the essential ingredient for the gravity phenomenon is the presence of strong variations or fluctuations of the Cooper pair density (a time- varying energy density). Woodward's experiment used a small array of capacitors whose energy density was varied by an applied 11 kHz signal. When these are vibrated up and down at the correct frequency so that they are going up when their mass is minimum and going down when their mass is maximum, then a small, constant, mass-force change is possible. Podkletnov's superconductor disk contained many Josephson junctions, which were radiated with a 3-4 MHz signal. At the layered interface, the Cooper pairs are moving upward, while the electron pair separations are moving downward.

These commonalties allow for ease in rewriting superconductor mass shift ∂m as

$$\partial m_{sc} = \frac{b\, f_{jj} P_{jj}}{G\, r_{sc} c^2}, \qquad (4)$$

where f_{jj} is the resonance frequency (in Hz) of the superconductor Josephson junctions, P_{jj} the effective combined power (in watts) of all the junctions, and r_{sc} is the density of the superconductor. Equation 4 then represents the mass change of the superconductor.

EXPERIMENTAL APPROACH

Repeating the original Podkletnov experiment has been a major undertaking within the Marshall Space Flight Center for several years. Confusion over the original experimental design and the ability to produce the large superconductors have been the major problems. Given these problems a much simpler experimental approach was devised to investigate the possible gravity connection. This approach has not been without problems.

The approach involved the replacement of the large (~1 kg) lead masses in a commercially available computerized torsion or Cavendish balance with a system that magnetically modulates an YBCO superconductor. A sketch of the proposed experiment is given in figure 4.

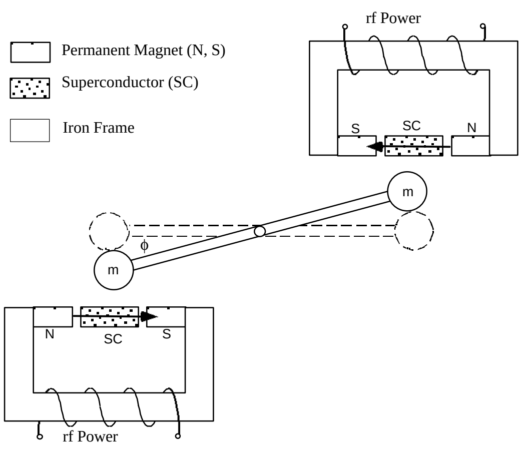


Figure 4. Sketch of the Cavendish balance experiment.

The measurement of the gravitation constant G (6.67×10^{-11} N·m^2/kg^2) using a Cavendish balance is a simple experiment, which is routinely performed by beginning physics students. Using Newton's universal law of gravitation, it is possible to express the angular displacement f of the beam in terms of directly measurable quantities

$$f = \frac{2GMml}{R^2 k} \qquad (5)$$

where M is the test mass, m is the mass attached to each end of the beam, l is the separation length of the beam mounted masses, R is the distance from the center of each test mass to the center of each beam mounted mass, and k is the torsion constant of the fiber supporting the beam (not shown).

Corrections

The use of the Cavendish balance as supplied with the large lead masses requires several corrections. Such as a correction for the gravitational torque on the beam and the cross torque between the opposite masses. These corrections are easily approximated and are applied to the smaller masses. Other corrections such as the variations in R can be averaged out over many data points.

In this experiment, the spherical large lead masses are being replaced by a much larger mass that is more like a rectangular box. Such a shape makes the calculation of these corrections much more complicated without extensive testing. The simple solution is to look at the things that are measurable versus those that are not and see how these change from one condition to the other. Equation 5 is then rewritten as,

$$k_c \left(\frac{M}{R^2} \right) = \left(\frac{k}{2Gml} \right) f \qquad (6)$$

where k_c is the correction to m the small mass.

Equation 6 can then be used in the formulation of a percent mass change $M\%$ even though the left side of the equation is unknown. For example, a percent mass change $M\%$ between a non-modulated superconductor mass M_1 and a modulated superconductor mass M_2 is just the ratio of the angular displacements f_1 and f_2, given by

$$M\% = \frac{M_2}{M_1} = \frac{f_2}{f_1} \qquad (7)$$

where the angular displacements are measurable.

Sensitivity

Equation 6 also is true for two different tests using two different mass weights. The change in the measured angular displacement of the torsion fiber will then be directly proportional to the change in the test mass. For example, the change in angular displacement df associated with an effective change in the test masses dM is given by

$$\frac{d\phi}{dM} = K_c G \quad (8)$$

The sensitivity of the device is therefore dependent on the magnitude of

$$K_c = \left(\frac{k_c}{R^2}\right)\frac{2ml}{k} . \quad (9)$$

By noting that the torsion constant $k = I/(2p/T)^2$ where

$$K_c = \left(\frac{1}{R^2}\right)\left(\frac{2T^2}{lp^2}\right) \quad (10)$$

which is independent of the smaller mass and any correction to it as long as the period T is measurable.

Based on the published characteristics of the as delivered Cavendish balance a numerical estimate for the sensitivity was determined to be

$$\frac{d\phi}{dM} = 0.3 \text{ microradians / gram} \quad (11)$$

for T = 120 sec, l = 30 cm, and R = 4.6 cm.

The commercially available Cavendish balance was chosen because it contained a computerized electronic detector known as a symmetric differential capacitive (SDC) control unit** to electronically measure the position of the beam as it rotates. The SDC is easily capable of measuring a displacement angle of 1 micro-radian. Therefore for a 0.5% weight change of a 300-gram superconductor, a displacement angle of 1.5 micro-radians would be detectable.

Testing has shown that the calculated displacement angle varies not with M but with M/R^2. This is due to the uneven mass density of the superconductor containment system or modulator that will be described later. That is, as the mass of the superconductor (or test mass) changes, the average density displacement of the modulator also changes, which in turn shifts the position of the modulators center of mass. This makes the determination of the percent mass change or equation 7 more difficult to determine. However, since we are only concerned at this point with seeing a change in the relationship between tests, the sensitivity to $1/R^2$ in equation 9 is a plus. In the general sense, the sensitivity as given in equation 11 is enhanced by the square of the difference in the shifted R values as a result of the test mass weight change.

Test Apparatus

** The SDC is an invention of Dr. Randall Peters; Research Consultant.

In order to operate the balance in the hand-off operation inside a liquid nitrogen cyro-tank, the balance was fitted into a structure and the motion of the large masses was automated using a National Instruments, nuDrive (model 4SX-411) stepper motor controller and a National Instrument's rack (PXI-1010) Chassis mounted computer (PXI-8156B) using Labview 5.1 software written specifically for this operation. The modified balance is shown in figure 5.

The large masses were replaced by a system, referred to as the modulator, which was required to modulate the superconductor sample with electromagnetic (EM) or rf energy. The modulator was composed of a superconductor, permanent magnets, an iron frame, a kHz coil, and an MHz antenna. Electrodes were placed adjacent to the superconductor to detect the hall current induced in the superconductor. A magnetic shield (1006 steel) was added due to an attraction problem with the balance's aluminum beam. A picture of the modified balance with the modulators is shown in figure 6 and a sketch of the modulator is shown in figure 7.

Figure 5. Automated Cavendish Balance.

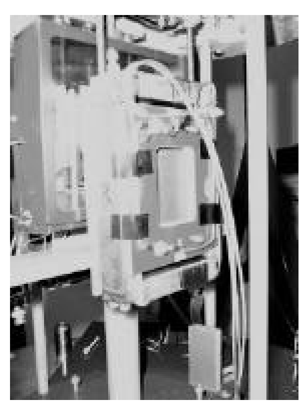


Figure 6. Modulator & Balance.

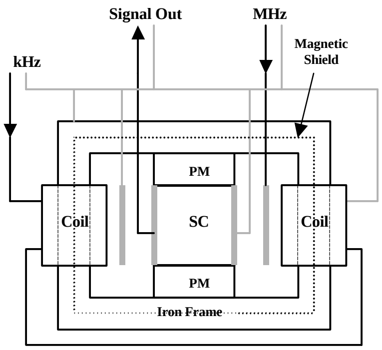


Figure 7. Sketch of Modulator.

The iron frame forms a magnetic circuit that directs the field through the superconductor and parallel to the balance's beam. The placement of the coil around the iron frame induces a time varying kHz field in the static field. The MHz antenna is placed near the coils also inducing a time varying field in the static field. The effect of these time varying fields were measured perpendicular to the static field.

The purpose of the static magnetic field produced by the permanent magnets was to induce currents in the superconductor about pinned flux sights and possibly the weaker holes about the grains, which would be much higher than that seen by the AC levitated superconductor in the Podkletnov experiment. The kHz modulation field would then act to break the pinning sites freeing the pinning currents to move according to the motion of the magnetic field in the superconductor material. In theory, the radiated MHz field reduces the resistance of the Josephson junction between the grain boundaries and to allow resistiveless passage of the currents throughout the superconductor.

The configuration of the superconductor then determines the mode of operation. That is, if the superconductor is composed entirely of sintered grains, the Heaviside force at the Josephson junction sights will dominate any gravity effect. On the other hand, if a non-superconducting, conductive layer is placed on the outward side of the sintered superconductor away from the balance; the electron motion across the boundary will produce a mass transit effect.

Instabilities

Several months were spent after the initial completion of the automated balance in determining and eliminating instabilities caused by the automation mechanism. The major mechanical problem was caused by the support apparatus, which would bend downward (ah gravity) as the modulator moved through the zero position. This allowed the spur gear to hit the support structure. Repositioning of the gear only made it hit other structures. The problem was fixed by grinding the top and bottom of the spur gear at an angle.

Placement of the drive motor also presented a problem. Due to the lack of support perpendicular to the balance beam, lead to the introduction of vibration. Placement of the motor such that the shaft rotation was in the plane of the modulator's motion and adding support structures provided a major reduction in the induced vibrations.

The deduction of these problems and the resulting fix thereof was hindered by the enclosure of the spur gear and the fact that some of the vibrations could only be detected by the analysis of the data. A data run was typically done overnight to allow the balance to stabilize. Three to five data cycles were typically required before stabilization occurred. One data cycle of about 35 minutes was required to get one dynamic angle measurement.

The only problem to arise during cooling in liquid nitrogen was with the electrical connections. Cooling below 170C caused intermittent signal disturbances. This was fixed by insulating the connections exposed to the liquid nitrogen temperatures.

TESTS RESULTS

Only one type of superconductor sample has been tested. It was composed of two layers; one of YBCO and one of PrBCO (Pr – Praseodymium). The substitution of Pr for Y was done to cause the layer to be a conductor with similar crystal structure to the YBCO. This sample was fabricated by the same manufacture producing the samples for the repeat of the Pokletnov experiment under a NASA SBIR phase II. Tests were conducted at room temperature and at liquid nitrogen (-196 C) temperature.

The YBCO superconductor only required < -180 C to become superconductive. The type K thermocouples used in the experiments flat lined between –186 C and –188 C in liquid nitrogen. Therefore to insure that the superconductor was in a superconductive state, tests were not conducted until a temperature < -186 C was optioned. The following graphs (figure 8 – 12) represent a data set using the same torsion wire. The numbers across the bottom (x

– axis) of each chart refers to the number of cycles from which each dynamic angle was calculated. The sequence is in order of time from start to finish of a data run. Each dynamic angle (or cycle) depended on the period of the torsion beam, but typically was between 30 and 40 minutes. The voltage value on the left (y -axis) of each chart refers to the calculated dynamic angle. The values have been left in its voltage value because the conversion factor for the control unit was stable between tests.

The results of the superconductor tests are base lined against a copper (Cu) sample.

No-Modulation

The results of the room temperature and the liquid nitrogen (i.e., superconductive) tests for the non-modulated or static magnetic field cases are shown in figure 8 and figure 9, respectfully.

As seen in the room temperature tests of figure 8, the calculated dynamic angles between the varying weighted masses increased with decrease mass weight due to the non-uniform density of the modulator (i.e., $1/R^2$). Additional tests were conducted using other weights composed of fiberglass epoxy, aluminum, and lead, which showed the same result.

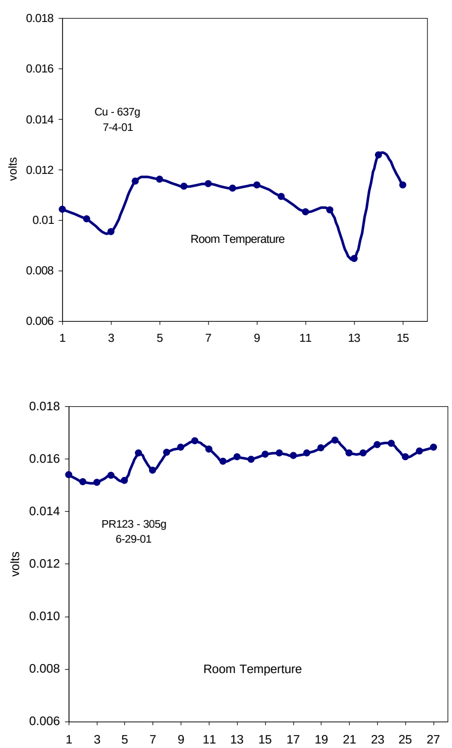


Figure 8: Dynamic Angle of copper sample (Cu) and superconductor sample (PR123) at room temperatures.

In the liquid nitrogen tests of figure 9, the tests were started when the superconductor was at superconductive temperatures and allow to warm-up over night. As shown, at the non-superconductive temperature of – 175 C there is a noticeable change in the values of the dynamic angles. (Approximately 0.06 v for the superconductor sample and 0.05 for the copper sample.) Earlier tests down to –170 C with the original lead masses in the balance, also show good results in the calculation of the gravitational constant, which changed by less than 2% from the room temperature value.

Instabilities noted at the beginning of the liquid nitrogen test of the superconductor sample warranted a repeat at the lower temperature. This was conducted immediately following the first test as not to disturb the balance. Figure 10 shows the data from the repeated run.

Figures 9 and 10 then show that the superconductor and the copper samples produced similar results at the lower temperatures.

EM Modulation

EM modulation tests were conducted at room temperatures and at liquid nitrogen temperatures for only the superconductor. These tests are shown in

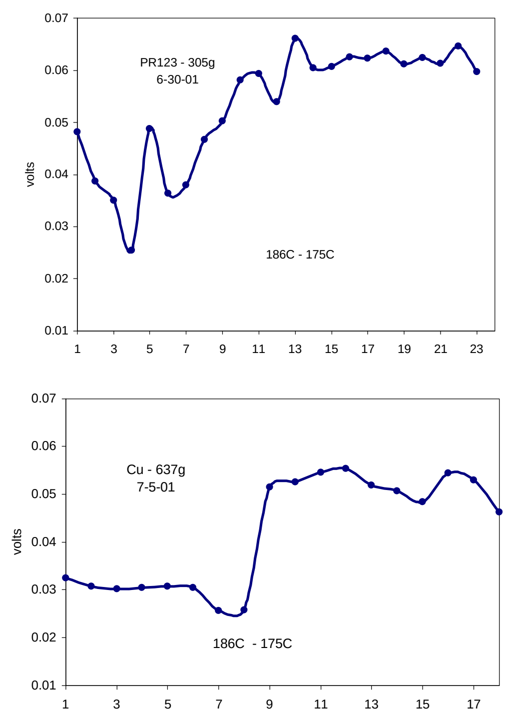


Figure 9: Dynamic Angle of copper sample (Cu) and superconductor sample (PR123) from superconductive

*temperatures to non-superconductive temperature***.**

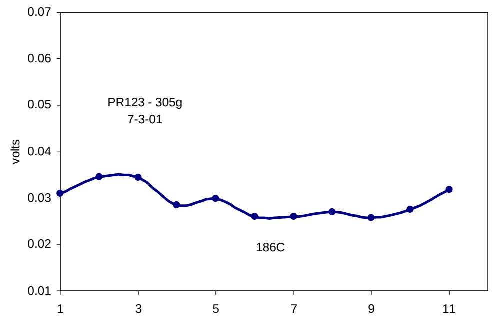
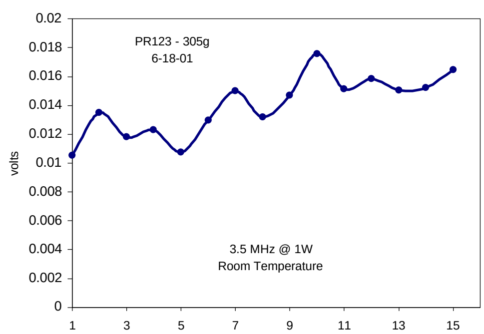


Figure 10: Dynamic Angle of the superconductor sample (PR123) at superconductive temperatures.

figure 11 and figure 12. The room temperature tests of figure 11 shows the effect of the MHz and kHz frequencies separately. In the liquid nitrogen test shown in figure 12, both the MHz and KHz frequencies are used together.

In both cases, the calculated dynamic angle increased over time. In the liquid nitrogen tests, the first two data points are with no EM modulation. This was done to detect a change before the boil off of the liquid nitrogen due to the rf heating of the iron frame, which was partially submerged in the liquid nitrogen. Rapid boil off reduced the superconductive run time from approximately six hours with no EM modulation down to two hours with EM modulation.



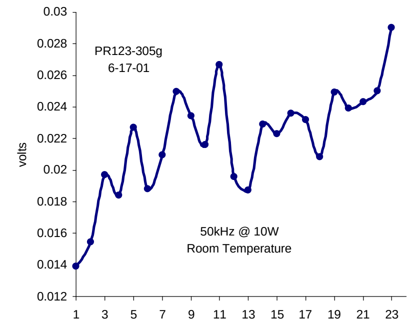


Figure 11: Dynamic Angle of the superconductor sample (PR123) at room temperatures with EM energy applied.

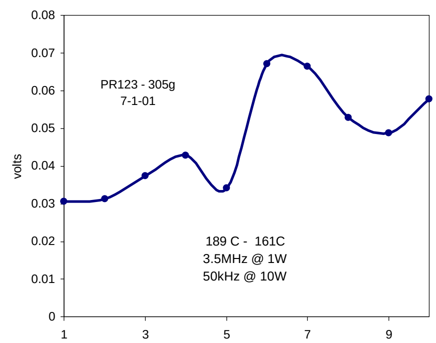


Figure 12: Dynamic Angle of the superconductor sample (PR123) at superconductive temperatures with EM energy applied.

CONCLUSIONS AND RECOMMENDATIONS

To summarize, we note that these exploratory experiments have been carried out in an attempt to quantify the effects of EM energy on a superconductor. The general conclusion is that the results of these tests gave a null result. That is, no conclusion at this time can be made to the EM effects on the superconductor. This conclusion is reached based on the increasing dynamic angle over time in both the room temperature and liquid nitrogen temperature tests.

Further, it is concluded that the balance is sensitive to mass changes at room temperature and down to approximately -175 C but not when the temperature is < -186. This conclusion was reached based on the similarities in the data for both the copper and superconductor samples in figure 9. However because no time varying temperature data was taken on these tests, further testing is required to pin point the actual shift point between –175 C and –186 C.

If a temperature at which the superconductor becomes superconductive and within the sensitivity of the balance is determined, it is recommended that non-EM modulated tests on the masses reported here and on a non-layered superconductor be conducted. Regardless of the results, a redesign of the balance is recommended to eliminate the EM modulation effects on the balance control unit and to reduce the heating effect of the modulator.

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SUPERLUMINAL BUT CAUSAL WAVE PROPAGATION

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Abstract: A series of experiments in recent years have shown that under carefully designed circumstances the group velocity, or even more surprisingly the energy velocity can exceed the speed of light in vacuum or become negative (abnormal velocities). These abnormal results have led some researchers to question the validity of special relativity, or at least cast doubt on the relevance of these principles to the aforementioned experiments. In this work series of experiments with single electromagnetic pulses measured in both time and frequency domain are described. It is seen that while these experiments verify the aforementioned abnormal velocities, they are not in contradiction with the principles of special relativity (Einstein causality). In this regard, the important concept of "front" or "Sommerfeld forerunner" is reintroduced, and it is argued that the only physical velocity required to obey the Einstein causality is the "front velocity."

I. Introduction

The fact that the group velocity of an electromagnetic wave packet (pulse) can exceed the speed of light in vacuum (become superluminal) has been demonstrated in many experiments using single photons [1, 2], at optical frequencies [3], and using microwaves [4-10]. As a starting point, an interested reader may consult the review by Chiao and the references therein [11]. Despite one's initial impression, the superluminal group or even energy velocities (defined as the ratio of the Poynting vector to the stored electromagnetic energy) are not at odds with the requirements of relativistic causality (Einstein causality), and indeed it can be shown that they must exist as the natural consequence of the Kramers-Kronig relations, which in themselves are a statement of the system linearity and causality [12-15].

The point that in the regions of anomalous dispersion, group velocity can become superluminal was first considered by Sommerfeld and his student Brillouin [16]. In their studies, they examined a sinusoidally modulated step-function propagating through a medium with Lorentzian dispersion. They identified five different velocities: phase, group, energy, Sommerfeld forerunner ("front[†]") and Brillouin forerunner velocities[‡]. However, with the passage of time, and for reasons unknown to the authors, while the first three velocity terms have received much attention in both undergraduate and graduate books, the latter two have not enjoyed the same status. This is even more surprising since, among the above velocities, it is only the

[†] To be more rigorous the term "front" refers to the onset of Sommerfeld forerunner propagation.
[‡] To be complete one has to add the term "signal velocity" defined as the velocity of the half maximum point to the list. However, by their own admission such a definition is arbitrary [16] and as discussed in Ref. (4) can become superluminal.

velocity of the "front" that must satisfy the requirements of Einstein causality under all circumstances. In other words, it is rather a naïve understanding of Einstein causality to equate the group velocity with the velocity of information transfer under all circumstances, particularly when one is concerned with the propagation of "attenuated traveling waves[§]."

Our objective here is to discuss the phenomenon of superluminal and negative group and energy velocities which generically is referred to as the abnormal velocities. In Sec. II a time-domain experiment used to detect the superluminal group velocities in the case of a one dimensional photonic crystal (1DPC) is described. Section III discusses a frequency-domain experiment used to demonstrate the same superluminal phenomenon. The case of superluminal or negative group and energy velocities for an inverted medium (medium with gain) or in the case of medium with negative index of refraction is considered in Sec. IV. Section V is intended to put the reader's mind at ease by providing some general arguments on why the abnormal velocities discussed in the previous sections are not in contradiction with the requirements of special relativity. Section VI is our condensed attempt is addressing the issue of superluminality in the limit of very weak light (very few photons). Our final remarks and a discussion for the general public can be found in Sec. VII.

II. Time-domain Experiment

Consider the problem of electromagnetic wave propagation through a periodic structure. Figure 1 shows an experimental setup used to detect the superluminal group velocity for a microwave wave packet tunneling through a 1DPC. A backward wave oscillator (BWO) was used to generate the pulse, and a mode converter (MC) was used to convert the TM_{01} mode of the BWO to a TE_{11}. The pulse was then radiated via a conical horn

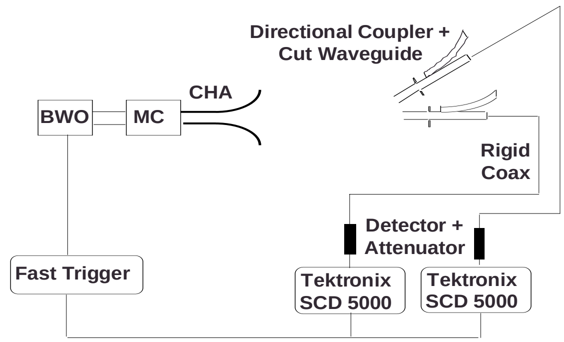

Fig. 1: Time-domain experimental setup

antenna (CHA). The frequency output of the source was tuned to the mid-gap frequency of the 1DPC at 9.68 GHz (FWHM of 100 MHz) and was detected by two HP 8470-B, Schottky diode detector (provided in pairs). The CHA radiation intensity was sampled along two distinct directions (paths), referred to as "side" and "center". A series of microwave pulses were fired in order to measure and then remove the time difference between the two paths due to the differences in cable lengths, internal detection of the oscilloscopes (Tektronix SCD 5000) and other incompatibilities. This measured time difference was electronically compensated such that the peaks corresponding to the pulses traveling through the "center" path and "side" path in the absence of the 1DPC arrived at the same time. At this point, the 1DPC was inserted along the "center" path and series of single pulse were fired. Figure 2 shows the result. It is seen that the peak of the wave packet propagating along the "center" path and tunneling through the 1DPC arrives (440 ± 20) ps earlier than the accompanying pulse propagating through free-space along the "side" path. This

§ We have used the term "attenuated traveling waves" in the same sense as in Ref. (17), although, sometimes the term evanescent is used to signify the same thing.

advancement in time for the tunneling pulse can easily be translated to a measure of the pulse group velocity, indicating that the tunneling wave packet propagated with a

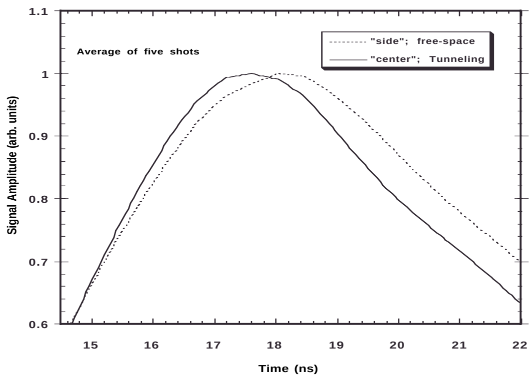

Fig. 2: Superluminal propagation for the tunneling pulse

group velocity $(2.38 \pm 0.15)\,c$.

Furthermore, the traditional view of pulse propagation through a region with high attenuation (regions of anomalous dispersion) held that the extreme

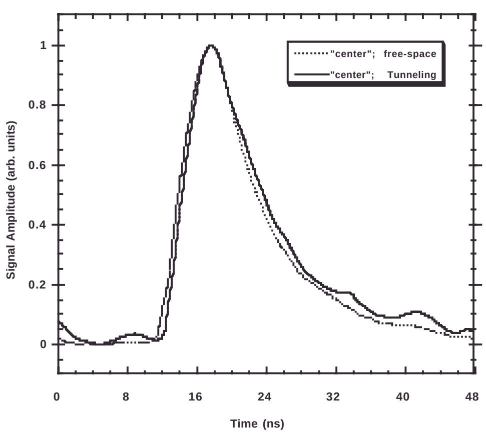

Fig. 3: A measure of the pulse broadening due to tunneling through the 1DPC. The two pulses have propagated along the same path ("center"); one in the free-space and the other through the 1DPC.

attenuation, coupled with the dispersion, would distort the signal to such an extent that the originally well defined wave packet and its peak would not be recognizable upon the emergence from such a medium [17] [16]. Figure 3 shows that in contrast to this common belief, the tunneling wave packet of Fig. (2) suffered minimal dispersion such that the FWHM of the pulse after tunneling was only increased by 1.5%. In obtaining this figure the tunneling wave packet was manually moved to later times as to make the comparison between the two pulses easier. A full description of the above experiment can be found in Ref. (4).

III. Frequency-Domain Experiment

In the last section the feasibility of measuring superluminal group velocities directly in time-domain was discussed. This abnormal behavior can also be demonstrated in frequency-domain. Figure 4 shows the

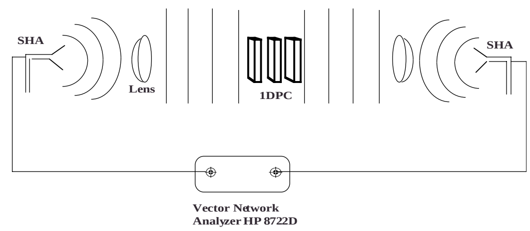

Fig. 4: Frequency-domain experimental setup

free-space setup used to detect the superluminal group velocities in frequency-domain. The setup consists of two K-band standard horn antennas (SHA) configured a transmitter and receiver and connected to ports 1 and 2 of an HP 8722D vector network analyzer (VNA). The radiated quasi continuous waves are collimated using two microwave lenses and the setup is enclosed in a anechoic chamber to reduce stray signals.

The essence of the approach is to measure *accurately* and *reliably* the transmission phase associated with the 1DPC. Once this quantity is measured, the group delay (τ_g) and group velocity (V_g) can be calculated according to

$$\tau_g = -\partial\,\phi / \partial\,\omega, \qquad (1)$$

$$\frac{v_g}{c} = \frac{L_{pc}}{c\,\tau_g} = \frac{-L_{pc}}{c\,(\partial\phi/\partial\omega)}, \qquad (2)$$

where ϕ is the transmission phase, and L_{pc} is the physical length of the 1DPC.

Fortunately, recent advances in non-coaxial (free-space) calibration techniques for VNA such as the “Thru-Line-Reflect” (TRL), [18, 19] make it possible to measured the transmission coefficient accurately and reliably. After calibrating the system (without the 1DPC), a reference plane of unit magnitude for transmission magnitude and zero phase for ϕ is established midway between the two SHAs. At this point, the 1DPC is inserted and the receiver horn is moved back exactly by a length equal to the thickness of the 1DPC (L_{pc}).

Figure 5 is the calculated (solid line)

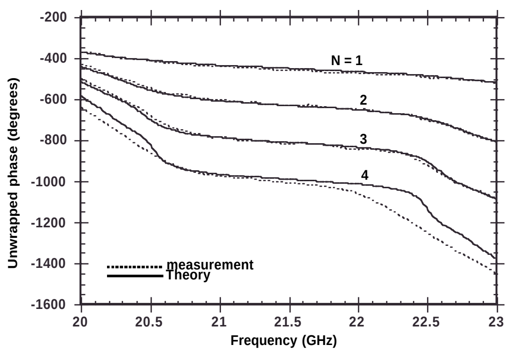

Fig 5: The unwrapped transmission phase for the 1DPC with various number of Eccostock® dielectric slabs.

and measured (dotted line) unwrapped phase for a 1DPC with four, three, two and one dielectric slabs (the spacer is always air). The theoretical calculations are based on the diagonalization of one period matrix, and is presented in Ref. (5).

According to Eqs. (1) and (2), to ascertain the group delay and group velocity the data presented in Fig. 5 must be differentiated. However, differentiating a noisy data amplifies the noise and may lead to spurious effects. To avoid the arbitrariness associated with smoothing, a best nonlinear least square fit of the experimental phase data is obtained. The parameters used in fitting the experimental data all match the actual variables very well and for the sake of brevity are not given here, but can be found in Ref. (5).

Figure 6 shows the result of the least square fit to the phase data of Fig. 5 together

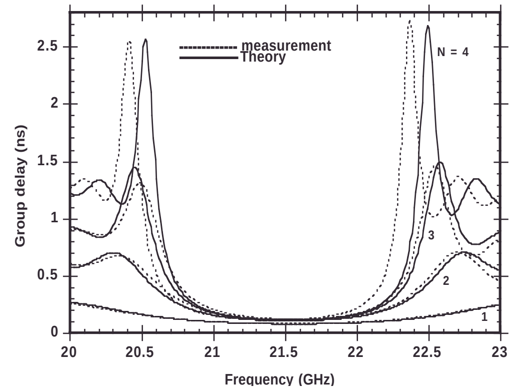

Fig. 6: Measured and calculated group delay for the 1DPC. The parameters used to obtain the fitted curves (measurement) and the calculated curves (theory) are given in Ref (5).

with Eq. (1), in order to determine the group delay in a 1DPC with one, two, three, and four dielectric slabs. Consequently, the normalized group velocity given by Eq. (2)

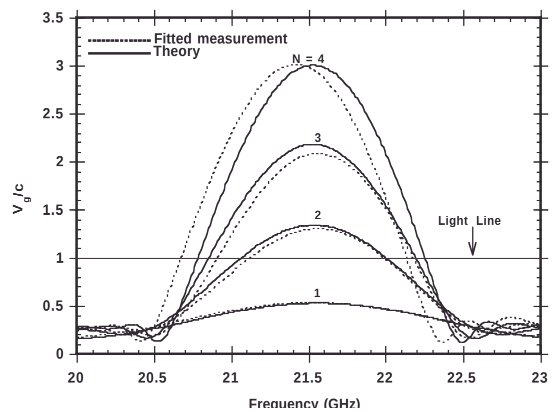

Fig. 7. Normalized group velocity for the 1DPC. The dotted curves are the measured results obtained from the fitted curves in Fig. 6 and Eq. 2. The solid curves are theoretically calculated.

can be obtained from the Fig. 6 and is shown in Fig. 7. Along with the velocities derived from the fit (dotted curves), the theoretical group velocities calculated from the measured values of thicknesses and indices are also shown (solid curves). As Fig. 7 indicates, in the case of *N=4* and *N=3*, a maximum superluminal group velocities 3 and 2.1 times c is observed. The results depicted in this figure cab be interpreted as the following. If one is to construct a pulse entirely composed of the frequency components for which the superluminal behavior is predicted, then the pulse is expected to propagate with group velocity exceeding c, similar to the situation discussed in the Sec. II.

IV. Abnormal Velocities in Inverted Medium and Medium with Negative Index

The circumstances under which the group or even energy velocity are abnormal are not limited to the evanescent wave propagation discussed so far. In this section three situations are described which exhibit the aforementioned abnormal behavior.

First, for an inverted medium (medium with gain) described by a Lorentz-Lorenz dispersion, the index of refraction is given by

$$n(\omega)=\left(1-\frac{\omega_p^2}{\omega_0^2-\omega^2-i\gamma\omega}\right)^{1/2} \qquad (3)$$

where ω_0 is the resonance frequency, γ is a small damping factor, and ω_p is the effective plasma frequency. Note that a negative sign precedes the second term under the square root due to the population inversion of the medium. A plot of the index of refraction for both the inverted and non-inverted medium is shown in Fig. 8. From the figure it is clear that for an inverted medium, in the limit of very low frequencies, the index is less than one implying that the phase velocity is superluminal. More importantly, at the low frequencies, the group velocity given by

$$V_g(0)=\frac{c}{\left[n(\omega)+\omega\, dn/d\omega\right]_{\omega\to 0}}=\frac{c}{n(0)}=V_p(0)>c \qquad (4)$$

is also superluminal. Under these circumstances the energy velocity (V_e), given by the ratio of Poynting vector (S), to the stored energy density (u), is also equal to the phase and group velocity and exceeds the speed of light in vacuum.

$$V_e=\frac{S}{u}=\frac{c}{n(0)}=V_p(0)>c \qquad (5)$$

The equivalence of the above three velocities is merely a statement of the fact that in the limit of low frequencies the medium is transparent and dispersionless [13].

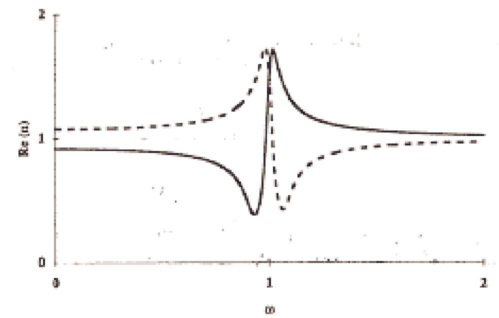

Fig. 8: The real part of the index of refraction for an inverted medium (solid curve) and non-inverted medium (dashed curve.)

Second, it is also possible to observe negative group velocities for electromagnetic (EM) pulses tuned slightly away from a gain line of an inverted medium. [14, 20-22]. The physical meaning of a negative group velocity can be explained as the following. Consider two cells of physical length L containing an inverted medium and vacuum as shown in Fig. 9.

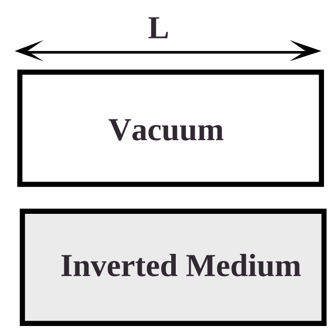

Fig. 9: Two cells of equal length containing inverted medium and vacuum.

The time difference between two well behaved identical EM pulses propagating through the lower (inverted) and the upper cell (vacuum) is given by

$$\Delta t = \tau_g - t_{vac} = \frac{L}{V_g} - \frac{L}{c} = \frac{L}{c}\left(n_g - 1\right) \quad (6)$$

where n_g is the group index. From the above equation it is clear that if the group index is zero the time difference between the two pulses is given by the negative of L/c In other words, when one of the EM pulses is at the exit face of the lower cell the other pulse is about to enter the upper vacuum cell. Stating this point differently, if one only consider a single cell containing the inverted medium, for a negative group index, the peak of the transmitted wave packet leaves the cell prior to the peak of the incoming wave packet entering the medium. It must be pointed out that as shown by Landauer [23-25] it is naïve to regard the peak of the outgoing pulse as the causal response of the medium to the peak of the incident pulse. The theoretical prediction by one of us [22] regarding the feasibility of detecting negative group velocity was recently verified in an experiment by Wang [26] in which the inverted medium was a cell containing Cesium vapor.

Finally, let us consider a situation for which the medium effective index is a negative value. A point worth emphasizing is the fact that for these media it is the effective index and not the actual material index which is negative. In other words, the wavelength of the incident wave is many times larger than the physical size of the components comprising the media, allowing one to characterize the over all response of the media in terms of an effective index.

The first theoretical work in this area was done by Veselago [27, 28], and the more recent interest in the subject was reignited by the work of Pendry [29, 30] and Smith et. al. [31, 32], which demonstrated the possibility of manufacturing these media at microwave frequencies. Figure 10, shows the dispersion relation for a negative index

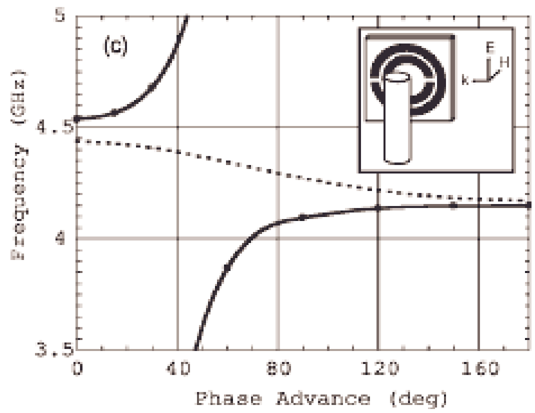

Fig. 10: The dispersion curves for a medium with negative effective index

medium, borrowed from Ref. (32). From the figure it is clear that for a certain frequency range, the derivative of the curve depicted in Fig. 10, (i.e. the group velocity) is negative. Even more surprising is the fact that the energy velocity, given by Eq. (7), is also negative, since in these media both permittivity and permeability are negative parameters.

$$V_e \propto \frac{\vec{E} \times \vec{H}}{\varepsilon \left|\vec{E}\right|^2 + \mu \left|\vec{H}\right|^2} \qquad (7)$$

The presence of negative group and energy velocities for the above media can be understood in the following manner. The

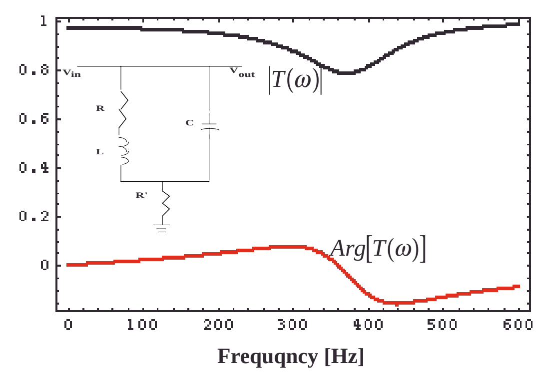

Fig. 11: Transmission magnitude and phase for the LRC circuit shown in the inset.

negative index medium, considered by Smith et. al. [31], is in essence a distributed

LRC transmission line that its response can be approximated by a lumped LRC circuit. The inset in Fig. 11 is a typical LRC circuit that exhibits negative group delay in the region of maximum attenuation[**]. Once again, if one is to construct an EM pulse mostly composed of frequency components having negative group delays, it is expected that the group and energy velocities for this EM pulse to be negative. We currently are pursuing the detection of the aforementioned abnormal velocities in the negative index media. We end this section by pointing out that in addition to negative velocities, the negative index medium has many other interesting properties such as inverted Doppler shift, Cherenkov radiation, and Snell's law.

V. Superluminal Velocities and Einstein Causality

In so far we have discussed situations for which the phase, group, and energy velocities are abnormal (superluminal or negative). The reader may began to wonder whether or not these abnormal velocities are in contradiction with the requirements of relativistic causality. The short answer to this question is that under no circumstances the so called "front velocity" may exceed the speed of light in vacuum, and in fact under all circumstances the "front velocity" is exactly luminal. In other words, the requirement of Einstein causality that no "signal" (information) can be transmitted superluminally is satisfied in all cases, since the "front velocity' is always luminal. This means that the presence of the genuine information should not be associated with the pulse maximum, half maximum, or the envelope, but indeed is contained within the singularities (points of non-analyticity) of the pulse. Because of the important role played by the "front" in satisfying the requirements of special relativity, let us briefly discuss some of the most general ideas associated with this concept. The interested reader may consult the Ref. (4) for more detailed analysis.

The essential point to remember is the fact that any *physically realizable* signal is restrictively time-limited. In other words, any electromagnetic signal created and later propagated through free-space or a 1DPC must be generated at a point in time and space. One can then always point to a time prior to which the signal did not exist. This point in time, or more precisely the transient "turn on times," are points of non-analyticity for which the amplitude of the pulse or its first or higher derivative are discontinuous.

The importance of these points of non-analyticity becomes clear when considering the following. While the future behavior of a truly analytical signal such as a Gaussian wave packet can be completely predicted by means such as a Taylor expansion (or a Laurent expansion for functions that are holomorphic in an annular region), the presence or arrival of the singularities do not yield themselves to such an extrapolation. Moreover, as discussed in the above, no *physically realizable* signal can be presented by an *entire function*[††] hence, any communication of information must involve the transmission of the "front". To summarize, there is no more information in a pulse peak or envelope that is not already contained within the earliest parts of the signal.

The mathematical proof that no signal (information) may be detected sooner than $t_0 = x/c$ can be seen via contour integration of an expression such as Eq. (8). Equation (8) describes the field at the position x and time t for a wave packet

[**] In obtaining Fig. 11, in contrast to the curves depicted in Fig. 5, a time dependency of $e^{-i\omega t}$ in place of $e^{j\omega t}$ was used. In other word, the group delay has the opposite sign of that shown in Eq. (1).

[††] An *entire function* is the one that is analytical everywhere in the complex domain.

impinging at normal incident on a medium characterized by an index of refraction, n, [33].

$$u(x,t) = \int_{-\infty}^{+\infty} \frac{2}{1+n(\omega)} A(\omega)\, e^{i k(\omega) x - i \omega t}\, d\omega , \quad (8)$$

$$A(\omega) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} u(x=0,t)\; e^{i \omega t}\, d\omega . \quad (9)$$

Transforming the integral in Eq. (8) into the complex domain and closing the contour over the upper-half-plan, along with requiring that the medium characterized by n to be causal, and that the incident wave packet has a "front," are sufficient conditions to show that the value of the integral is identically zero for $t \le t_0 = x/c$ or equally for velocities, $V = x/t > c$. The condition that the medium characterized by n is causal, means that for this medium the effect can not proceed the cause. Mathematically this is expressed as $G(\tau) = 0$ for $\tau < 0$, where $G(\tau)$ is the susceptibility kernel given by

$$G(\tau) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \left[\varepsilon(\omega)/\varepsilon_0 - 1\right] e^{-i\omega\tau}\, d\omega . \quad (10)$$

For times immediately after t_0, ($t >\approx t_0$) the earliest part of the signal known as the Sommerfeld forerunner or precursor can be detected. The frequency of oscillation and the field amplitude for the Sommerfeld forerunner are discussed by Mojahedi et. al. [4, 34]. To summarize those results, the frequency of oscillation is given by

$$\omega_s = \sqrt{G'(0)} \Big/ \sqrt{2\left(\frac{t}{t_0} - 1\right)} , \quad (11)$$

where $G'(0)$ is the time derivative of the susceptibility kernel [33] evaluated at $t = 0$. Furthermore, for the incident wave packet proportional to t^m (m is an integer) the Sommerfeld forerunner is described by a Bessel function of order m according to

$$u(x,t) \approx a\left(\frac{t-t_0}{\gamma}\right)^{m/2} J_m\left(2\sqrt{\gamma(t-t_0)}\right); \quad (12)$$

$$\gamma = \frac{G'(0)\, t_0}{2}; \qquad for\ t > t_0 .$$

From the above discussion it is clear that, for a given medium if the quantity $G'(0)$ is known, the calculation of the Sommerfeld forerunner frequency of

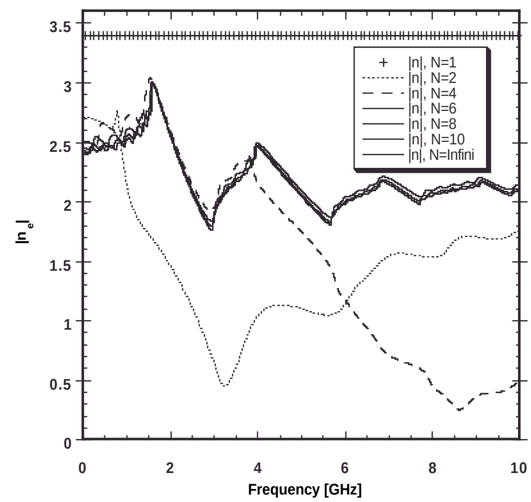

Fig. 12: Effective index for a 1DPC. The structure parameters are: $d_i = 1.76$ cm, $d_j = 1.33$ cm, $n_i = 1$, $n_j = 3.40$

oscillation and functional form is relatively straight forward. In other words, if one is capable of calculating $\varepsilon(\omega)/\varepsilon_0 - 1 = n^2 - 1$ for a 1DPC, undersized waveguide, or any other photonic barrier used in the superluminal experiments, then one can perform the inverse Fourier transform and the differentiation operation to obtain $G'(0)$. For example, let us consider the case of 1DPC used in the experiments discussed in Sections. II and III.

At the normal incidence the dispersion relation ($K\ vs.\ \omega$) can be obtained from

$$\cos(K\,\Lambda) = \cos\left(\frac{\omega\, n_i\, d_i}{c}\right)\cos\left(\frac{\omega\, n_j\, d_j}{c}\right) - \frac{1}{2}\left(R + R^{-1}\right)\sin\left(\frac{\omega\, n_i\, d_i}{c}\right)\sin\left(\frac{\omega\, n_j\, d_j}{c}\right), \quad (13)$$

where R is the ratio of the indices given by $R = n_i/n_j$, Λ is the one-period length $\Lambda = d_i + d_j$, and K is the Bloch wave vector. The above equation can be used to solve for the real and imaginary parts of the Bloch wave vector, and Eqs. (14)-(16), below, can in turn be used to transform the photonic crystal spatial dispersion [Eq. (13)] to a more manageable temporal dispersion

$$\mathrm{Re}(n_e) = n_e' = \frac{c}{\omega}\,\mathrm{Re}[K(\omega)], \quad (14)$$

$$\mathrm{Im}(n_e) = n_e'' = \frac{c}{\omega}\,\mathrm{Im}[K(\omega)], \quad (15)$$

$$|n_e| = \left[(n_e')^2 + (n_e'')^2\right]^{1/2} = \frac{c}{\omega}\,|K(\omega)|. \quad (16)$$

The results are shown in Fig. (12) which displays our first attempt in obtaining an effective index for a 1DPC, with 1, 2, …, and infinite number of dielectric slabs. The next step is to perform the Fourier transform indicated by Eq. (10), followed by the differential operation evaluated at time equal to zero. Having obtained the quantity $G'(0)$, the frequency of oscillation and the functional form of the Sommerfeld forerunner in a 1DPC can be arrived at with the help of Eqs. (11) and (12).

VI. Superluminal Propagation and Quantum Noise in the Limit of Very Weak Pulse.

The question of superluminality in the limit of very weak pulse (one or few photons) was considered in a recent work [35]. For the sake of brevity, we refer the interested reader to Ref. (36) for a complete and detailed analysis of the situation. Here, we suffice to mention that according to Aharonov et. al. [36] in the limit of few photons, signal must be exponentially large in order to distinguish it from the quantum noise. In other words, the signal-to-noise ratio becomes vanishingly small. In Ref. (36) this assertion is investigated and it is seen that if the condition stated by Aharonov et. al. is replaced by a weaker condition, the signal-to-noise ratio can exceed unity even for one photon pulse. It is worth mentioning that the original experiment by Chiao and Steinberg, [2] although involved the detection of single photon, but the results were interpreted in terms of statistics of many photons.

<u>VII. Concluding Remarks: A Discussion for General Public</u>

A simple yet interesting description of superluminal propagation can be found at web link http://www.abqjournal.com/scitech/180964scitech11-19-00.htm.
This article written by John Fleck, the science writer for Albuquerque Journal, tries to explain our newly published paper in *Physical Review E* to the general public. To use John's analogy consider two dragsters competing against each other, driving the same exact cars and traveling the same exact distances. However, whereas one of the dragsters travels through air (vacuum if you like) with the maximum allowable speed, the other driver travels through a series of barriers normally thought to slow his car. The question is then the following: What does the referee at the end line observe? The answer depends on the referee detection equipment. If the referee is well equipped with the most sensitive and expensive detection systems he or she will observe that the front bumpers of the two cars arrive at the finishing line at exactly the same instance. The referee will also observe that the bulk (the main body, the cockpit and the driver) of the dragster's car who tunneled through the barriers reaches the end line

sooner than his challenger. Interestingly, if the race is decided by arrival of the cars main body or if the referee is not equipped with the most sensitive detection apparatus, he or she will invariably call the race for the tunneling dragster.

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EXAMPLE ONLY

NASA Breakthrough Propulsion Physics Project

Call for Research Proposals

NOTE:

THIS SOLICITATION HAS ENDED.

DO NOT SUBMIT ANY PROPOSALS OR OTHER MATERIALS TO THE BPP PROJECT.

The text of this call is provided here as an example of the type of work that is sought by the project and the criteria against which proposals will be judged.

CONTENTS:

[Return to the BPP home page]

OMB Approval No. 2700-0042

RESEARCH AND DEVELOPMENT REGARDING "BREAKTHROUGH" PROPULSION

NASA Research Announcement
Soliciting
Proposals for Research

for the Period
Ending
February 26, 1999
NRA-99-LeRC-1
ISSUED: November 9, 1998

Mail Proposals To:
NASA Glenn Research Center
Attn: MS 500-306/ NRA-99-LeRC-1
21000 Brookpark Rd.
Cleveland, OH 44135

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GLENN RESEARCH CENTER
CLEVELAND, OH 44135-3191

NASA RESEARCH ANNOUNCEMENT
RESEARCH AND DEVELOPMENT REGARDING "BREAKTHROUGH" PROPULSION

This NASA Research Announcement (NRA) solicits proposals for Research and Development in the area of Breakthrough Propulsion Physics. Proposals should aim to incrementally advance physics to address critical unknowns, make-or-break issues, or curious effects related to the long-range goal of achieving at least one of the following propulsion challenges: (1) Discover propulsion methods which eliminate or dramatically reduce the need for propellant; (2) Discover methods for achieving the shortest possible travel times (includes the study of methods to circumvent observed limits); and (3) Discover new modes of on-board energy generation to power the propulsion devices. Topics of interest include experiments and theories regarding: the coupling of the fundamental forces, force-producing effects, contents and properties of space, the motion of matter and energy through spacetime, interactions with spacetime, energy exchange mechanisms, energy sources, and observed anomalous effects. Because these propulsion challenges are presumably far from fruition and perhaps even impossible, a special emphasis is to identify affordable, near-term, and credible research that could make measurable and incremental progress toward these propulsion challenges.

Participation is open to all categories of organizations: industry, educational institutions, other nonprofit organizations, NASA centers, and other U.S. Government agencies.

Appendix A provides technical information on the general areas in which proposals are sought. Appendix B provides proposal submission information, including information on the criteria against which proposals will be judged, applicable only to this NRA. Appendix C contains general guidelines for the preparation of proposals solicited by an NRA.

Glenn Research Center anticipates making between 3 to 7 awards this year as a result of the NRA totaling $500,000. It is anticipated that the NRA will result in grants/contracts with a value of approximately $50K to $150K each. However, each offeror should propose a budget that accurately reflects their Statement of Work. Offerors may submit proposals for 1, 2, or 3 year efforts.

Funds are not presently available for awards under this NRA. The government's obligations to make awards is contingent on the availability of appropriated funds from which payment for award purposes can be made and on the receipt of proposals which the government determines are acceptable for award under this NRA. A proposal that is sufficiently meritorious, but that cannot be accepted during its initial review under this NRA due to funding limitations, may be considered for subsequent awards throughout the fiscal year of the NRA unless the offeror requests otherwise.

Offerors are hereby informed that the technical investigations in the fields covered by this Announcement may require access to technical data, the export of which is controlled under the Export Control Act, Title 50, Unites States Code App. §2401-20, the Arms Export Control Act, Title 22, United States Code §2751 - 2794 or both. No award will be made to any offeror unless the Grants Officer is satisfied that performance of the grant or cooperative agreement will not involve an illegal export of technical data under either statute. All presentations, charts, publications, journals, etc. which may fall under the export control act or limited exclusive rights to data (LERD), must be submitted to the GRC Intellectual Property Officer or Technical Monitor for subsequent approval.

It is requested that questions related to the preparation and submission of proposals be submitted by **November 24, 1998**, so that answers to these questions can be posted for all prospective offerors. The questions and answers will be posted on **December 11, 1998**. Proposals may be submitted at any time during the period ending **February 26, 1999**. Proposals received after this date will be rejected. It is requested that organizations planning to submit a proposal notify NASA of their intent by **December 18, 1998**. The Letter of Intent is being requested for planning the peer review team for this solicitation. Prospective offerors are hereby notified that non-Government evaluators will take part in the evaluation of this NRA. Evaluations will involve a peer review process using the Breakthrough Propulsion Physics project's Research Prioritization Criteria (Appendix B). These criteria will be used to provide an initial ranking, and then multiple, *different* approaches will be selected from the top ranking candidates to the limit of the available funding. It is anticipated that Fiscal Year 1999 funds will be allocated for this NRA, with awards planned for **June 1999**.

Solicitation Number: **NRA-99-LeRC-1**

NAIS Posted Date: November 9, 1998

CBDNet Posted Date: November 9, 1998

Response Date **February 26, 1999**

Classification Code: A -- Research & Development

Submit Proposals to*:

NRA-99-LeRC-1

NASA Glenn Research Center

Gary Golinski, MS 500-306

21000 Brookpark Rd.

Cleveland, OH 44135

Number of Proposal Copies Required: **7**

Any questions related to the preparation and submission of the proposal should be directed to:

Gary A. Golinski

NASA Glenn Research Center

21000 Brookpark Rd.

Attn.: MS 500-306

Cleveland, OH 44135

Phone (216) 433 - 2790

Fax (216) 433 - 2480

E-Mail: Gary.A.Golinski@GRC.nasa.gov

Appendix A

Appendix B

Appendix C

Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004

NASA Breakthrough Propulsion Physics Project

Call for Research Proposals

APPENDIX A

TECHNICAL INFORMATION

NOTE:

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APPENDIX A

NRA-99-LeRC-1

RESEARCH AND DEVELOPMENT REGARDING "BREAKTHROUGH" PROPULSION

TECHNICAL INFORMATION

BACKGROUND

In 1996, NASA established the "Breakthrough Propulsion Physics" (BPP) project to assess the prospects for developing breakthrough advancements in propulsion physics to surpass the limits of rockets. The BPP project, managed by Glenn Research Center, is part of the "Space Transportation Research" (STR) of the "Advanced Space Transportation Program" (ASTP), managed by the Marshall Spaceflight Center. The ASTP is a comprehensive strategy for advancing space propulsion technology for the next 25 years and spans the nearer-term improvements all the way through seeking the breakthroughs that could ultimately enable interstellar missions [reference #1].

Rockets are fundamentally limited by propellant. Propellant mass requirements rise exponentially with increases in payload, destinations, or speed. This limit cannot be overcome with *engineering* refinements: it is based on the very *physics* of rocketry. Historically, the limits of existing technologies have been surpassed when new methods, with completely different operating principles, are found and developed [ref. 2]. To surpass the limits of rockets and thereby dramatically reduce the expense and duration of space missions, new propulsion *physics* is sought.

To determine if science has evolved sufficiently to where progress can be made toward discovering new propulsion physics, the BPP project is employing the following strategy: The first step, completed in 1996, was to identify the propulsion challenges and to define the programmatic methods for seeking credible progress toward such incredible possibilities[3]. The second step, started in 1997 and continuing, is to support conference sessions, workshops and internet sites to foster collaborations and to identify the critical issues and affordable research candidates[4-7]. Concurrent with this is to identify related works[8-15]. The third step is this research announcement. Research tasks are now sought that can incrementally advance physics to address critical unknowns, make-or-break issues, or curious effects related to achieving the far-future goal of revolutionizing spaceflight and ultimately enabling interstellar voyages. The fourth step, planned for two years after having supported research, will be to assess if the progress gained is worth sustaining the project. This next assessment may be in the form of a workshop, a scientific advisory board, or both. If progress is promising, increased funding will be sought for such research. If not, then the project will be put on hold until further significant scientific developments emerge.

Just as past scientific advancements provided the foundations for past technological revolutions (e.g., radio, aircraft, rockets, atomic power, transistors, lasers, etc.), the same can be expected for further scientific advancements. There are several unresolved areas of physics and several intriguing developments from recent scientific literature that might provide paths toward new propulsion physics. The coupling of the four fundamental forces is still not fully understood; general relativity and quantum physics are still incompatible theories; and astronomical observations reveal conflicting data regarding the amount of mass in the universe, to name but a few examples. In addition to such unfinished physics, theories and phenomena have emerged in recent scientific literature that are intriguing. Quantum tunneling experiments have revealed a phenomenon[16] that some interpret as faster-than-light[17]. Theories using general relativity have examined methods and issues of circumventing the light-speed limit (wormholes[18,19], warp drives[20], and Krasnikov tubes[21]). Astronomical observations reveal an expansion rate for the universe that appears to be accelerating - contrary to our current understanding[22,23]. Gamma ray bursts have been observed that indicate an energy mechanism beyond that explainable with current theories[24]. Experiments and theories of quantum physics[25] indicate the possible existence of vacuum fluctuation energy, including a force-producing effect (Casimir effect[26]). Anomalous weight reductions have been reported over spinning superconductors[27,28]. And there are many other examples[29-32]. It should be emphasized that many of these developments are still too new to have been confirmed or dismissed, and are far from becoming breakthroughs in the near future, if at all. What they do provide, however, are additional starting points for propulsion-focused research.

Although many of these intriguing developments are already being explored by the scientific community to determine their validity and relevance to the age of the universe, the mystery of missing matter, or the coupling of the fundamental forces, there has not been an effort to apply these developments specifically to the goals of spaceflight. Without such a focus it will be difficult to determine if new propulsion methods can seriously arise from emerging physics. In the first step of the scientific method, where one clearly formulates the problem to guide the search for knowledge, this NASA project has a unique problem: how to propel spacecraft as far and as fast as possible and with the least amount of effort. Such a focus will present different lines of inquiry than general physics alone. By asking different questions and looking along a different path, this project also provides an opportunity for physicists to search for discoveries that may otherwise be overlooked or delayed. The value to humanity of achieving a propulsion breakthrough would be enormous. Even considering a low probability of success, the benefits-versus-risk are high enough to warrant this modest initial inquiry.

TECHNICAL GOALS (PROPULSION CHALLENGES)

The following three challenges were identified as the breakthroughs that could revolutionize spaceflight and ultimately enable human interstellar voyages. Consistent with the Horizon Mission Methodology[33], these challenges represent goals that are presently *impossible* to achieve. This is a deliberate strategy to force the search for *new* knowledge rather than just deeper investigations of what is already known to be possible. This strategy is also intended to articulate goals whose achievement could ultimately provide enormous benefits to humanity.

> (1) MASS: Discover new propulsion methods that eliminate or dramatically reduce the need for propellant. This implies discovering fundamentally new ways to create motion, presumably by interactions with the properties of space or by the interactions between matter and spacetime, including the possibility of manipulating gravity or inertia.
>
> (2) SPEED: Discover how to attain the ultimate transit speed to dramatically reduce travel times. This implies discovering a means to move a vehicle at or near the actual maximum speed limit for motion through space or by some other means, such as by interactions with spacetime itself, to *circumvent* normal limits.
>
> (3) ENERGY: Discover fundamentally new modes of onboard energy generation to power these propulsion devices. This third goal is included since the first two breakthroughs could require breakthroughs in energy generation, and since the physics underlying the propulsion goals is closely linked to energy physics.

PROPOSALS SOUGHT:

Proposals are invited for conducting experiments or advancing theories that address critical unknowns, make-or-break issues, or curious effects related to achieving at least one of the propulsion challenges stated above. Candidate tasks and topical areas suitable for this research announcement are listed below. Proposed research can address one or more of these tasks and one or more of these topical areas. Note that these lists only represent examples and are not meant to be comprehensive. Other relevant research that is not explicitly shown on these lists may also be proposed. Also, the examples offered below are not listed in any preferential order. For a more detailed description of the prioritization criteria that will be used to rank the proposals, see Appendix B.

Candidate Tasks:

Design and/or conduct experiments or empirical observations to:

- Collect more data about a relevant phenomenon or theory, which has already been independently confirmed in the peer-reviewed literature, with a special emphasis on those aspects that are most relevant to the propulsion challenges.

• Perform an *independent* test of a relevant anomalous effect (or device) that has not yet been independently confirmed in the peer-reviewed literature.

• Test a relevant theory that has not yet been independently confirmed in the peer-reviewed literature.

• Apply phenomena and/or theories, which have already been independently confirmed in the peer-reviewed literature, to create a propulsive or power-producing effect.

Conduct theoretical and/or analytical work to:

• Identify the remaining critical knowledge gaps and/or make-or-break issues related to the propulsion challenges.

• Compile and analyze data on relevant phenomena and/or theories, which have already been reported in the peer-reviewed literature, with a special emphasis on those aspects that are most relevant to the propulsion challenges.

• Assess and/or compare the propulsion relevance of phenomena and/or theories which have already been independently confirmed in the peer-reviewed literature.

• Assess the validity and propulsion relevance of phenomena and/or theories that have not yet been independently confirmed in the peer-reviewed literature.

• Develop a theory to explain an anomalous effect, which has already been independently confirmed in the peer-reviewed literature, with a special emphasis on those aspects that are most relevant to the propulsion challenges.

• Apply theories, which have already been independently confirmed in the peer-reviewed literature, to describe how to create a propulsive or power-producing effect.

• Develop a theory to suggest how to create a propulsive or power-producing effect.

• Advance a relevant theory to where it can be empirically tested.

Topical Areas:

- Coupling of the fundamental forces.

- Force-producing effects.

- Contents and properties of space with respect to candidate reaction masses and energy sources.

- Motion of matter and energy through spacetime (including quantum tunneling and quantum non-locality).

- Interactions with spacetime (including wormhole, warp drives, or other transport-related effects).

- Energy exchange mechanisms, including kinetic energy.

- Energy sources.

- Anomalous physical effects.

SCOPE OF PROPOSALS

As the name implies, this project is specifically looking for *scientific* advancements that may ultimately lead to propulsion breakthroughs. It is not looking for further *technological* refinements of existing methods. Such refinements are being explored in other programs under the ASTP. Instead, this project looks beyond the known methods, searching for further advances in science from which *genuinely new* technology can eventually emerge - technology to surpass the limits of existing methods.

Since the project's goals are presumably far from fruition while the support is sought in the near-term, it is mandatory that the long-range challenges be broken down into smaller, affordable, near-term steps. A special emphasis is to identify the immediate questions and issues raised by comparing emerging physics to the propulsion challenges. Proposals are therefore required to suggest only an incremental task related to the ultimate goals (tasks that can be completed within 3 years or less). Also, from this point of view, "successful completion" of a research task is defined as learning more about reaching the breakthrough, rather than actually *achieving* the breakthrough. Negative test results are still progress.

Also, since this NASA project is interested in advancements which can eventually lead to new technology, there is a decided preference toward experimental work. Appendix B contains a more detailed description of the criteria that will be used to rank the proposals.

DELIVERABLES - REPORTS

Funded tasks are required to deliver a Final Report, Quarterly Technical Progress Reports, and for those tasks that exceed one-year duration, Annual Progress Reports. In addition, any data acquired during the completion of the task shall also be delivered. Quarterly Technical Progress Reports are required during the duration of the funded work and shall each be between 1 to 2 pages in length. The Final Report shall be in a form suitable for submission to a peer-reviewed journal. The Final Report also serves as the annual progress report for the final year of the task, for those tasks exceeding one year in duration. Annual Progress Reports are required for tasks that exceed one-year duration, and shall be 10 to 15 pages in length each.

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Last update: May 13, 2004

NASA Breakthrough Propulsion Physics Program

Call for Research Proposals

APPENDIX B

PROPOSAL SUBMISSION INFORMATION

NOTE:

THIS SOLICITATION HAS ENDED.

DO NOT SUBMIT ANY PROPOSALS OR OTHER MATERIALS TO THE BPP PROJECT.

The text of this call is provided here as an example of the type of work that is sought by the program and the criteria against which proposals will be judged.

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APPENDIX B

NRA-99-LeRC-1

RESEARCH AND DEVELOPMENT REGARDING "BREAKTHROUGH" PROPULSION

PROPOSAL SUBMISSION INFORMATION

This section gives the requirements for submission of proposals in response to this announcement. The research project described in the typical proposal submitted under this announcement must be directed by a Principal Investigator who is responsible for all research activities and may include one or more Co-Investigators. Offerors must address all the relevant selection criteria in their proposal as described in "Research Prioritization Criteria" and must format their proposal as described in this section. Additional general information for submission of proposals in response to NASA Research Announcements may be found in Appendix C. Where the guidelines in Appendix B (specific to this NRA) and Appendix C (general NRAs) differ, Appendix B takes precedent for this announcement.

LETTER OF INTENT

Organizations planning to submit a proposal in response to this NRA should notify NASA of their intent to propose by electronically sending a Letter of Intent via e-mail to: **Gary.A. Golinski@GRC.nasa.gov**.

If electronic means are not available, you may mail Letters of Intent to the address given for proposal submission in the following section. Facsimile transmission of the Letter of Intent is also acceptable. The fax number is (216) 433-2480.

The Letter of Intent, which should not exceed two (2) pages in length, must be typewritten and include the following information:

- The potential Principal Investigator (PI), position, organization, address, telephone, fax, and e-mail address.
- A list of potential Co-Investigators (Co-I's), positions, and organizations.
- General scientific/technical objectives of the research.

The Letter of Intent should be received no later than **December 18, 1999**. The Letter of Intent is being requested for information and planning purposes only, and is not binding on the signatories. Institutional authorizations are not required. The Letter of Intent allows NASA to better match expertise in the composition of peer review panels with the response from this solicitation.

PROPOSAL

The proposal should not exceed **18** pages in length, exclusive of appendices and supplementary material, and should be typed on 8-1/2 x 11-inch paper with a 10- or 12-point font. Extensive appendices and ring-bound proposals are strongly discouraged. Reprints and preprints of relevant work will be forwarded to the reviewers if submitted as attachments to the proposal.

Seven copies of the proposal must be received at the address below by February 26, 1999, 4:30 PM EST to assure full consideration. NASA can not receive deliveries on Saturdays, Sundays or federal holidays. Late proposals will be rejected.

Send proposals to the following address:

Gary A. Golinski

NASA Glenn Research Center

21000 Brookpark Rd.

Attn.: MS 500-306

Cleveland, OH 44135

Phone (216) 433 - 2790

Fax (216) 433 - 2480

E-Mail: Gary.A.Golinski@GRC.nasa.gov

Proposals submitted in response to this Announcement must be typewritten in English and contain at least the following information (in addition to the required information given in Appendix C) in the format shown below:

- Title Page

- Executive Summary (replaces abstract specified in Appendix C, item 7d) (1-2 pages)

- "BPP NRA Task Summary Form" (2 pages)

- Research Project Description containing the following elements:

  - Statement of the critical issues, premise, or hypothesis being addressed and its relation to the Breakthrough Propulsion Physics (BPP) technical goals (propulsion challenges).

  - Description of the work to be performed, including both a one-paragraph summary and a longer description containing sufficient technical detail to allow evaluation by NASA of technical feasibility and cost.

  - Description of any special equipment or facilities used to perform the work.

  - Review of relevant research literature.

- Management plan appropriate for the scope and size of the proposed project, describing the roles and responsibilities of the participants

- Statement of permission for, or restrictions against, NASA’s use of the proposal information submitted on the "BPP NRA Task Summary Form" in future assessment reports for the Breakthrough Propulsion Physics program.

- Appendices:

  - Budget plan with proposed annual costs for the duration of the proposed task, using the "Budget Summary Form" (1 page). The information desired is explained below.

- Summary of current and pending support for the Principal Investigator and Co-Investigators.

- Complete current curriculum vita for the Principal and Co-Investigators, listing education, publications, and other relevant information necessary to assess the experience and capabilities of the senior participants.

The title page must clearly identify the research announcement to which the proposal is responding, title of the proposed research, Principal Investigator, institution, address and telephone number, total proposed cost, proposed duration, and must contain all signatories.

The executive summary should succinctly convey, in broad terms, what the offeror intends to do, how the offeror plans to do it, and why it is important to the NASA Breakthrough Propulsion Physics program. This executive summary replaces the proposal abstract as required in Appendix C, item 7d.

Each proposal should include the "BPP NRA Task Summary Form," and the "Budget Summary Form," as included at the end of this Appendix. Proposals are also required to provide signed copies of other Representation and Certification forms as offered and described at: http://ec.msfc.nasa.gov/msfc/pub/reps_certs/midrange/.

Proposal Cost Detail Desired: Sufficient proposal cost detail and supporting information will facilitate a speedy evaluation and award. Dollar amounts proposed with no explanation (e.g., Equipment: $58,000, or Labor: $10,000) may cause delays in evaluation or award. The proposed costing information should be sufficiently detailed to allow the Government to identify cost elements for evaluation purposes. Generally, the Government will evaluate cost as to reasonableness, allowability, and allocatability. Enclose explanatory information, as needed. Each category should be explained. Offerors should exercise prudent judgment as the amount of detail necessary varies with the complexity of the proposal.

Option on the Use and Disclosure of Proposal Information: Information contained in proposals is normally used for evaluation purposes only, as described in Appendix C, item 7c. However, with the offeror’s written permission, the proposal information contained on the "BPP NRA Task Summary Form" is desired for inclusion into future

NASA assessment reports about the BPP program. Such publicly available reports focus on the critical issues facing the program to suggest future courses of action, and are useful in advocating for additional research funds. Any such assessment report that involves information obtained by this announcement will not be published until after the selection and award process for this announcement is completed. If the offeror wishes this proposal information to be considered for inclusion in such assessment reports, this must be explicitly stated in writing by the offeror, and the information which may and may not be disclosed in such assessment reports, must be clearly delineated by the offeror. Otherwise, all materials will be used per the guidelines in Appendix C, item 7c.

EVALUATION AND SELECTION

Evaluation Process:

Selections will be made following a two-stage peer review process described below. The first stage will numerically rank the proposals, and the second stage will select multiple proposals the top ranking candidates. The final decisions will be made by a NASA selecting official. A proposal that is scientifically and programmatically meritorious, but not selected for award during its initial review, may be included in subsequent reviews, for a period of up to 1 year, unless the offeror requests otherwise.

In the first stage of the review process, proposals are subject to scientific review by discipline specialists in the area of the proposal. Proposals will be reviewed by a combination of in-house and selected external reviewers, with due regard for conflict-of-interest and protection of proposal information. These external reviewers may be from other NASA centers, other Government Labs, Universities, or Industry. Each proposal will be evaluated by several evaluators, who will give numeric scores using the "Research Prioritization Criteria" of the BPP program, described below. The scores will be forwarded to NASA for compilation and use in the second stage of the review process.

The second stage of the review process will be conducted by a smaller team of Government reviewers, again with due regard for conflict-of-interest and protection of proposal information. This team will recommend a diversified set of research from the top ranking proposals to the limit of available funding. A suite of *different* approaches is desired to "diversify the portfolio" since it is still too early to tell which research paths will lead most directly to breakthroughs. This means that the proposals selected for award may not necessarily be selected contiguously from the highest-ranking set. For example, if the top two ranking proposals are both to perform an experimental test of a given theory, "A", and the third ranking proposal is to test a different theory, "B", then it is the prerogative of the selecting official to award the best proposal on "A" and the proposal on "B" while skipping the second-ranking proposal on "A", if this supports diversification of research. The final decisions will be made by the NASA selecting official.

Upon completion of deliberations, offerors will be notified regarding proposal selection or rejection. Offerors whose proposals are declined will have the opportunity of a verbal debriefing with a NASA representative regarding the reasons for this decision. Additional information on the evaluation and selection process for NRA solicitations is given in Appendix C.

Research Prioritization Criteria:

This list shows those factors that will be numerically scored to measure the relative value of proposals. For those criteria that are particularly unique to this NRA, more detailed descriptions follow. The following section replaces Section 13 of Appendix C. Please note that there is a deliberate preference toward experimental work that addresses critical make-or-break issues of physics, issues that are directly relevant to any of the Breakthrough Propulsion Physics program's goals (propulsion challenges). Within these criteria proposals will be judged for their relevance, credibility, and scientific quality.

Technical Relevance:

A* Directness to program (must seek advances in physics that are relevant to propulsion or power).

B* Magnitude of potential gains for Goal #1 [Mass] + Goal #2 [Speed] + Goal #3 [Energy] (must be relevant to seeking significant gains for at least one of the three propulsion challenges).

C Lineage (will it lead to further relevant advancements?)

D Status to be achieved upon completion of task (using scientific method levels as a metric)

(D-E)* Magnitude of progress to be gained by the work, as measured by the difference between the status to be achieved upon completion of the task, D, and the status today, E. (using scientific method levels as a status metric).

Probability of Success:

F* Based on credible foundations (references must be cited)

G* Compared with current credible approaches (references must be cited)

H* Must be, or be leading toward, a credible discriminating test.

I* Probability of successful task completion (based on credentials and realism of proposal)

Programmatic Merit:

J Breadth of work (experiment, theory, and/or comparative study)

[Note: experiments are considered closer than theory to becoming technology, and are ranked higher]

K Triage (will it be done anyway or must this program support it?)

L Time required to complete task (reciprocal scoring factor)

M Funding required (reciprocal scoring factor)

* Mandatory Criteria

Total Score: Each of the lettered criteria above will receive a numeric score which will then be multiplied together to arrive at a total score for each proposal. This evaluation system is set up such that a *failure* to meet any mandatory criteria (zero score on criteria) will result in a total score of zero. In this solicitation, criteria A, B, (D-E), F, G, H, and I are all *mandatory* criteria (which means that it is possible to get a score of zero if a criteria is not met); criteria A, B, D, I, and J are all high priority criteria; and criteria C, E, F, G, H, K, L, and M are all lessor priority criteria.

Near-Term Focus to Long-Range Goals: (Criteria A, C, [D-E], H, J, L and M) The program's goals are presumably far from fruition while the support is sought in the near-term. To address this paradox it is essential that the long-range goals be broken down into smaller, affordable, near-term steps. A special emphasis is to identify the immediate questions and issues raised by comparing emerging physics to the propulsion challenges. Proposals are therefore required to suggest only an incremental task related to addressing the critical unknowns, make-or-break issues, or curious effects related to achieving at least one of the propulsion challenges, and are graded inversely to their duration and cost. Also, from this point of view, "successful completion" of the research task is defined as learning more about reaching the breakthrough, rather than actually *achieving* the breakthrough. Negative test results are progress.

Directness to seeking propulsion breakthroughs: (Criteria A and B) As the name implies, this program is specifically looking for *scientific* advancements that may ultimately lead to propulsion breakthroughs. Further *technological* refinements of existing methods are not being sought under this announcement. Such refinements are being explored in other areas of the Advanced Space Transportation Program. Instead, this program looks beyond the known methods, searching for further advances in science from which *genuinely new* technology can eventually emerge - technology to surpass the limits of existing methods. As such, it is mandatory that the proposed work seek advances in science that are in some way relevant to the program's three propulsion challenges or any critical issues related to these goals (criteria A). Also, this program is most interested in concepts that can lead to the highest potential gain (criteria B). For example, addressing an issue that pertains to *eliminating* propellant will rank higher than addressing issues related to simply *reducing* propellant (all other factors being equal). Also note that the magnitude of gain scores for each propulsion goal sum. This means that investigations that pertain to more than one goal can accumulate a higher score.

Breath of Proposed Work: (Criteria [D-E] and J) Since this NASA program is interested in advancements which can eventually lead to new technology and since empiricism is necessary to validate theories, there is a decided preference toward experiments over analytical studies. Experiments, being hardware, are considered closer than theory to becoming technology. Also, experiments are considered a more direct indicator of how nature works. Theories are *interpretations* to explain observations of nature, while the empirical data *is* nature. Another concern is that some theories are not likely to lead to physical effects that could be engineered into a space vehicle (e.g., black hole theories). The most desired work is experiments that are coupled with theory. Experiments that are backed by a sound theoretical foundation provide a means to numerically assess of the potential utility and scalability of the effects beyond just a single demonstration experiment. The next preference is for experimental work by itself, for example to independently verify a claimed anomalous effect. The next preference after that is theoretical work by itself. Lowest on this priority scale is work that only involves comparative studies of existing approaches or literature searches.

Metrics of Progress: (Criteria D, [D-E], F, G, H and I) To demonstrate to the program sponsors that progress is being made in the short time-frame of funding cycles, it is necessary to have a scale to measure the status of an approach. Patterned after the "Technology Readiness Scale" used to compare engineering progress, the Scientific Method has been adapted to measure the scientific progress that precedes technology. This scale, listed below in order of increasing maturity, is used explicitly in criteria D and E, and implicitly in criteria F, G, H, and I.

READINESS LEVELS

To Specify Starting and Completion Point of Proposed Research

Note that the scientific method levels below have two descriptors; "Emp" for approaches based on the emergence of a *new* empirical effect, and "Thry" for approaches based on theory.

PRE SCIENCE

(Emp) Observations of an unconfirmed anomalous effect have been reported (includes claims of unverified devices), or

(Thry) A *correlation* between a desired goal (or unsolved problem) and the existing knowledge base has been articulated.

STEP I: PROBLEM FORMULATED

(Emp) In the case of prior observations of an unconfirmed anomalous effect, an experiment has been defined that can collect the data required to isolate and characterize the effect, or

(Thry) A goal (or problem) has been defined specifically enough to identify the specific remaining knowledge gaps toward achieving the goal (or solving the problem).

STEP II: DATA COLLECTED

(Emp) An anomalous effect has been *independently* verified or attributed to misinterpretations of conventional effects, or

(Thry) The relevant data to fill the critical knowledge gaps, identified in the previous step, have been collected through experiment, observation, or mathematical proof (this level includes assessments of theory using mathematical analysis).

STEP III: HYPOTHESIS PROPOSED

(Emp) A mathematical representation of the physical principles underlying an anomalous effect has been offered to explain the effect and predict additional (testable) effects, or

(Thry) A mathematical representation of the relation between physical phenomena has been offered that addresses the goal (or problem) formulated previously.

STEP IV: HYPOTHESIS TESTED & RESULTS REPORTED (= TECH READINESS LEVEL 1)

The hypothesis has been tested by comparison to observable phenomena or by experiment sufficiently to determine if it appears viable, and the results reported. Given this definition, this level is equivalent to the Technology Readiness Level 1: "Basic principles observed and reported." (NOTE: In the context of this BPP program, testing of a hypothesis must be *empirical*; that means it must be done by comparison to observable phenomena or by experiment, rather than just by mathematical proof. Although mathematical proof can be used to test the consistency of a theory against the *known* laws of physics, such a mathematical test alone is not sufficient to warrant a "Step IV." Instead, a mathematical test of a theory warrants a "Step II.")

TRL 1: TECH READINESS LEVEL 1: BASIC PRINCIPLES OBSERVED & REPORTED

TRL 2: APPLICATION CONCEPTUAL DESIGN FORMULATED [propulsion or power device]

(Note this level is ONLY valid for ideas based on credibly verified principles that have already achieved Sci. Method Step IV = TRL 1. A proposed device whose underlying principles have not yet been credibly and *independently* verified is considered as being Pre Science.)

TRL 3: CONCEPTUAL DESIGN TESTED ANALYTICALLY OR EXPERIMENTALLY

Once a Breakthrough Physics approached has matured past the point of TRL 3, it is ready to proceed onto a technology program, separate from the BPP Program.

Probability of Success Criteria (Credibility With Vision): (Criteria F, G, H and I) One of the challenges of seeking breakthroughs is ensuring credibility without sacrificing openness to new, potentially breakthrough perspectives. This is particularly challenging since genuinely new ideas often extend beyond the established knowledge base, or worse, can *appear* to contradict this base. In other words, a *genuinely newand correct* idea is very likely to *appear* non-credible until proven. Also, it is common when soliciting new ideas to receive a large number of clearly non-credible submissions. To address this challenge, the "Probability of Success" criteria are used. These criteria are aimed to: (1) concentrate on credible *empirical* data (how nature is observed to work) rather than depending on current theories or paradigms (how nature is *interpreted* to work), (2) compare the new idea’s value to existing approaches, (3) ensure that the new idea can eventually be put to a test, and (4) look for the characteristic signs of non-credible work. It should be noted that these credibility criteria do not check if an idea is *correct*, but rather check to see if the idea is credibly constructed, and is leading to a credible correctness test. Because these success factors are critically important in the review process, detailed descriptions of these criteria are offered below.

Based on Credible References: (Criteria F) The proposed work must be based in some way on data or theories that are in the peer-reviewed literature. In the case of new theories that are not yet in the literature, the offeror must cite peer-reviewed references of the data or phenomenon with which they are claiming consistency. It is not necessary that the offeror agree with current interpretations of this data, but it is mandatory that the theories are consistent with credible empirical evidence. In those cases where the offeror asserts that they are building upon work that has already achieved Level I (Problem Formulated) or higher on the Scientific Readiness Levels, they must cite references to support this. For example, if they are claiming that they are testing a hypothesis that is already in the peer reviewed literature, they must cite that reference. In cases where *unconfirmed* anomalous effects are being discussed, the offeror must site relevant peer-reviewed references. If prior tests of the effect have been performed and reported in the literature, these references must be cited (to position them for addressing Criteria G). If the effect has not yet been reported in the literature, then the offeror must at least cite peer-reviewed references that describe related phenomena to demonstrate why the phenomena is anomalous (and to position them for addressing Criteria G).

Comparison to Current Credible Approaches: (Criteria G) To ensure that an idea is oriented toward the goals of the program, and to ensure that the offerors have done their homework, it is required that the proposal articulate how the proposed work compares to existing approaches, relative to the goals of breakthrough propulsion. This not only checks for relevance, but also positions the work to address the next criteria: a discriminating test. In the case of new theories, it is mandatory that the new theories be compared to the contemporary theories that address the same phenomena. Reference citations for the contemporary theories are required. The comparison must explain why the new theory would be more advantageous to the propulsion challenges than the contemporary theories. In cases where an anomalous effect is being investigated that has already been confirmed in the peer-reviewed literature, the proposal must explain why the effect might be advantageous to the propulsion challenges and why the proposed investigation is more applicable to addressing the propulsion challenges than prior or ongoing investigations into the effect. Reference citations for the prior or ongoing investigations are required. In cases where *unconfirmed* anomalous effects are being investigated, the proposal must explain why the effect (if genuine) might be advantageous to the propulsion challenges and why the proposed investigation is more applicable to the propulsion challenges than existing or past investigations into the effect. This discussion must acknowledge other possible conventional explanations for the anomaly. In the case where prior null test results have been published, the offeror must cite these and explain why the prior tests were incomplete or why a reinvestigation is warranted. Reference citations for the prior or ongoing investigations are required.

Must be, or be leading toward, a discriminating test: (Criteria H) It is required that the proposed work be leading toward a discriminating test or actually be a discriminating test. If a discriminating test can be completed within the budget and time guidelines requested of proposals, it is necessary that the test actually be proposed. Otherwise, it is sufficient to propose to advance a theory toward testable predictions or to design an experiment to perform a make-or-break test. The offeror must identify the critical make-or-break issues for their immediate area of investigation. Also, the proposed next-step must be consistent with the scientific method, with due consideration for the current status of the topic as specified by the offeror. Also note that, depending on the status of the proposed task, *independent* verification may be warranted. In the case of new theories, it is mandatory that the new theories are at least matured to the point where mathematical models are offered . Then, either mathematical analysis; further development to predict testable effects; comparison to credible empirical observations; or experimental tests must be proposed that can bring the theory closer to a correctness resolution. An actual empirical test is preferred. In cases where an anomalous effect is being investigated that has already been confirmed in the peer-reviewed literature, the next logical step would be to develop a theory to describe the anomaly. The criteria stated previously for new theories would then apply to this situation as well. In cases where *new, unconfirmed*, anomalous effects are being investigated, a discriminating test must be suggested that could distinguish between possible conventional explanations or whether this is a genuine new effect. The work will be considered more credible if the proposal concentrates only on the experimental methods rather than on speculating on a new theory for the unconfirmed effect.

Probability of Successful Task Completion: (Criteria I) Successful completion of the research task is defined as learning more about reaching the breakthrough, rather than actually *achieving* the breakthrough. Negative test results are progress. What is required for successful completion is that the work reaches some credible resolution and that this conclusion is clearly communicated. Evaluation of this criteria includes consideration of the realism of the proposed work, its cost and schedule, and on the credentials of the proposed research team and facilities. Note that, depending on the status of the proposed task, *independent* verification may be warranted.

BPP NRA TASK SUMMARY FORM INSTRUCTIONS

To expedite the evaluations of proposals, please complete the "BPP NRA Task Summary Form" in addition to providing the more detailed proposal. This form encapsulates key information that will be used in the review process. Where applicable, the letter for the relevant prioritization criteria is shown on the form in brackets, e.g., [A].

1. Proposal Title: [Self-explanatory]

2. Principle Investigator: [Self-explanatory]

3. Critical Issue or Premise Addressed:

Please provide a brief narrative, one to four sentences, to identify the critical unknowns, make-or-break issues, or curious effects being addressed by the proposed research. Because the Breakthrough Propulsion Physics program goals are presumably far from fruition (and may even be impossible to achieve), a special emphasis is to identify the immediate questions and issues raised by comparing emerging physics to the program goals.

4. Proposed Task:

Please provide a brief narrative, one to six sentences, to introduce the work being proposed. Since the Breakthrough Propulsion Physics program goals are presumably far from fruition while the support for the program is sought in the near-term, it is essential that the long-range goals be broken down into smaller, affordable, near-term steps; steps that are consistent with the scientific method. Proposals are therefore required to suggest only an incremental task related to the ultimate goals, a task that can be completed within one to three years. To help answer this question, please review the "Readiness Levels" presented in Appendix B. From this scale, specify the next-step that is required to make the next increment of progress, given the current status of the concept being addressed. Also note that a final report, suitable for submission to a peer reviewed journal, is a required deliverable.

5. Directness to the BPP Program Goals: [Self-explanatory]

6. Magnitude of Potential Gain Relative to the BPP Program Goals:

For each of the three program goals (Propulsion Challenges) stated in Appendix A, select which statements offered on the Summary Form (block 6) that best describes the ultimate achievable performance of the concept being addressed by the proposal. Granted, it may be difficult to predict this ultimate impact since the concepts may be far from fruition, but make the best judgment possible.

7. Level of Progress Before and After:

Using the "Readiness Levels" detailed in Appendix B, specify the status to be achieved upon completion of the proposed task ("after"), and of status today ("now") for the concept being addressed. Answer this question within the limits of the specific, incremental issue or effect being addressed by the proposal. Note that "successful completion" is defined as completing the proposed work and learning more about reaching the breakthrough, rather than actually achieving the breakthrough. Negative test results are still progress.

8. Breadth of Proposed Work: [Self-explanatory]

9. Upon completion of the proposed work, what would be the next likely step to continue progress?

Assuming the proposed work is completed and the results are favorable, specify the likely next research step(s). Identify what step is required to make the next increment of progress. Please provide only a brief narrative, one to four sentences.

10. References- citations to support proposed work: [Self-explanatory]

It is only necessary to list the most relevant supporting references on this summary form, so long as the complete list is provided in the more detailed task proposal.

11. References- citations for comparisons to alternative approaches: [Self-explanatory]

It is only necessary to list the most relevant supporting references on this summary form, so long as the complete list is provided in the more detailed task proposal.

12. Examples of prior work:

Cite examples of prior publications, completed grants, or contracts that demonstrate your ability to successfully complete the proposed work. It is only necessary to list the most relevant supporting examples on this summary form, so long as the complete information is included in the rest of the proposal.

13. Why must this NASA BPP program fund this work?

In some cases, it is possible that other programs may support proposed research. Please provide only a brief narrative, one to three sentences, explaining why this NRA is the most appropriate forum to support the proposed research.

14. Time: [Self-explanatory]

15. Cost: [Self-explanatory]

16. Permission to publish this information:

Information contained in proposals is normally used for evaluation purposes only, as described in Appendix C, item 7c. However, with the offeror's written permission, the proposal information contained on the "BPP NRA Task Summary Form" is desired for inclusion into future NASA assessment reports about the BPP program. Such publicly available reports focus on the critical issues facing the program to suggest future courses of action, and are useful in advocating for additional research funds. Any such assessment report that involves information obtained by this announcement will not be published until after the selection and award process for this announcement is completed. If the offeror wishes this proposal information be considered for inclusion in such assessment reports, this must be explicitly stated in block 16 of this form, and signed by the offeror, and the information which may and may not be disclosed in such assessment reports, must be clearly delineated by the offeror. Otherwise, all materials will be used per the guidelines in Appendix C, item 7c.

Three options are provided for the use of materials on this form:

(1) Permission is granted for the use of *any* of the information supplied on this form for future, publicly available, NASA reports.

(2) Permission is granted for the use of *some* of the information, as identified on the form, for future, publicly available, NASA reports (Specify which blocks can be used for the NASA reports).

(3) None of the information supplied on this form may be used for any purpose other than for the evaluation of the proposal.

BPP NRA TASK SUMMARY FORM page 1 of 2

1 **Proposal Title:**
2 **Principle Investigator:**

3 **Critical Issue or Premise Addressed [A, B, H]:** *(Brief Narrative)*

4 **Proposed Task [A, H]:***(Brief Narrative)*

5 **Directness to the BPP Program Goals [A]:** Which of the following statements best describes the directness of your proposal to one or more the BPP program goals? *(check only one):*

[_] Deals with emerging science, but the relevance to the BPP goals is not yet clear.

[_] Addresses critical physics issues **related to** one or more of the goals.

[_] Directly addresses the physics of producing net forces, high-speed transport, or abundant energy.

[_] Suggests a specific **method** or **device** for producing net forces, motion, or energy.

6 **Magnitude of Potential Gain Relative to the BPP Program Goals [B]** For each of the three program goals below, which of the following statements **best** describes the ultimate achievable performance of the concept being addressed *(check only one for each goal)*: **GOAL #1: Transportation Without Propellant [B1]:** [_] Probably not applicable to this goal. [_] Unknown potential impact. [_] Pertains to significant gains beyond existing methods *(e.g., rockets, beamed energy, etc.)*. [_] Pertains to fully achieving the goal of creating propulsion with no, or minimal , propellant. **GOAL #2: Maximum Speed Transportation [B2]:** [_] Probably not applicable to this goal. [_] Unknown potential impact. [_] Pertains to significant gains beyond existing methods *(e.g., rockets, beamed energy, etc.)*. [_] Pertains to circumventing the light-speed limit. **GOAL #3: Abundant Transportation Energy [B3]:** [_] Probably not applicable to this goal. [_] Unknown potential impact.	7 **Status After [D], and Now [E]:** Using the "Readiness Levels" below, specify the status to be achieved upon **completion** of the proposed task **("after")**, and of status **today** for the concept being addressed **("now")**. *(check only one in each column)*: **After Now** **[D] [E]** [_] [_] Pre Science [_] [_] I. Problem Formulated [_] [_] II. Data Collected [_] [_] III. Hypothesis Proposed [_] [_] IV. Hypothesis Tested & Results Reported (= Tech Readiness Level 1) [_] [_] TRL 1: Basic Principles Observed & Reported [_] [_] TRL 2: Application Conceptual Design Formulated [_] [_] TRL 3: Conceptual Design Tested Analytically or Experimentally 8 **Breadth of Proposed Work [J]:** Which of the following statements **best** describes the type of work proposed *(check only one)*: [_] Comparative study, data collection, or literature search. [_] Theoretical work only, without empirical investigations.

[_] Pertains to significant gains beyond existing methods *(e.g., chemical, nuclear, antimatter.)*. [_] Pertains to fully achieving the goal of providing nearly inexhaustible onboard energy.	[_] Experimental tests or empirical observations only. [_] Experiment or empirical observations coupled with theory.

BPP NRA TASK SUMMARY FORM page 2 of 2

9 **Upon completion of the proposed work, what would be the next likely step to continue progress? [C]:** *(Brief Narrative)*
10 **References- Citations of supporting work [F]**:

11 **References- Citations of comparisons to alternative approaches [G]**:

12 **Examples of prior work [I]:**

13 **Why must this NASA BPP program fund this task? Why is this work not supported elsewhere? [K]:**
(Brief Narrative)

14 **Time Required to Complete Task: [L]**	15 **Cost [M]:**
[_] Up to 1 year [_] Up to 2 years [_] Up to 3 years	________ First year ________ Second year ________ Third year **______ TOTAL**

16 **Permission to use the information submitted on this form, in whole or in part, for future publicly available NASA reports:**

[_] Permission is granted for the use of *any* of the information supplied on this form for future publicly available NASA reports.

[_] Permission is granted for the use of *only that information shown in the following blocks*, for future publicly available NASA reports:

Block Numbers:____.

All other information may **only** be used for the evaluation of the proposal.

[_] None of the information supplied on this form may be used for any purpose other than for the evaluation of the proposal.

Signature of Principle Investigator: Date:

_____________________________________ __________________________________

BUDGET SUMMARY FORM

From ___________ to _____________

RECIPIENT'S COSTS NASA USE ONLY

	A	B	C
1. DIRECT LABOR	$_________	$_________	$_________
(salaries, wages, fringe benefits)			
2. OTHER DIRECT COSTS:			
a. Subcontracts	$_________	$_________	$_________
b. Consultants	$_________	$_________	$_________
c. Equipment	$_________	$_________	$_________
d. Supplies	$_________	$_________	$_________
e. Travel	$_________	$_________	$_________
f. Other	$_________	$_________	$_________
3. INDIRECT COSTS ____%	$_________	$_________	$_________
4. OTHER APPLICABLE COSTS	$_________	$_________	$_________
5. SUBTOTAL-ESTIMATED COST	$_________	$_________	$_________
6. LESS PROPOSED COST SHARING (if any)	$(_________)	$(_________)	$(_________)
7. CARRYOVER FUNDS (if any)	$(_________)	$(_________)	$(_________)
a. Anticipated Amount $_________			
b. Amount used to reduce budget			
8. TOTAL ESTIMATED COST	$_________	$_________	xxxxxxxxx
9. PROPOSED COSTS VALID THROUGH (date)	____________________		
APPROVED BUDGET	xxxxxxxxx	xxxxxxxxx	$_________

Instructions

1. Provide a complete budget summary sheet for year one and separate estimates for each subsequent year.

2. Recipient's proposed costs should be entered in Column A. Columns B and C are for NASA use only. Column C represents the approved grant budget.

3. Provide as attachments to the budget summary the detailed computations of estimates in each

cost category with narratives to fully explain
proposed costs.

Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004

NASA Breakthrough Propulsion Physics Project

Call for Research Proposals

APPENDIX C
INSTRUCTIONS FOR RESPONDING TO NASA RESEARCH ANNOUNCEMENTS
FOR SOLICITED PROPOSALS
(June 1995)

NOTE:
THIS SOLICITATION HAS ENDED.

DO NOT SUBMIT ANY PROPOSALS OR OTHER MATERIALS TO THE BPP PROJECT.

The text of this call is provided here as an example of the type of work that is sought by the project and the criteria against which proposals will be judged.

CONTENTS:

[Return to the BPP home page]

APPENDIX C
NRA-99-LeRC-1

RESEARCH AND DEVELOPMENT REGARDING "BREAKTHROUGH" PROPULSION
INSTRUCTIONS FOR RESPONDING TO NASA RESEARCH ANNOUNCEMENTS
FOR SOLICITED PROPOSALS
(June 1995)

1. Foreword

a. These instructions apply to NASA Research Announcements. The "NASA Research Announcement (NRA)" permits competitive selection of research projects in accordance with statute while preserving the traditional concepts and understandings associated with NASA sponsorship of research.

b. These instructions are Appendix I to 1870.203 of the NASA Federal Acquisition Regulation Supplement.

2. Policy

a. Proposals received in response to an NRA will be used only for evaluation purposes. NASA does not allow a proposal, the contents of which are not available without restriction from another source, or any unique ideas submitted in response to an NRA to be used as the basis of a solicitation or in negotiation with other organizations, nor is a pre-award synopsis published for individual proposals.

b. A solicited proposal that results in a NASA award becomes part of the record of that transaction and may be available to the public on specific request; however, information or material that NASA and the awardee mutually agree to be of a privileged nature will be held in confidence to the extent permitted by law, including the Freedom of Information Act.

3. Purpose

These instructions supplement documents identified as "NASA Research Announcements." The NRAs contain programmatic information and certain requirements which apply only to proposals prepared in response to that particular announcement. These instructions contain the general proposal preparation information which applies to responses to all NRAs.

4. Relationship to Award

a. A contract, grant, cooperative agreement, or other agreement may be used to accomplish an effort funded in response to an NRA. NASA will determine the appropriate instrument.

b. Grants are generally used to fund basic research in educational and nonprofit institutions, while research in other private sector organizations is accomplished under contract. Contracts resulting from NRAs are subject to the Federal Acquisition Regulation and the NASA FAR Supplement (NHB 5100.4). Any resultant grants or cooperative agreements will be awarded and administered in accordance with the NASA Grant and Cooperative Agreement Handbook (NHB 5800.1).

5. Conformance to Guidance

a. NASA does not have mandatory forms or formats for preparation of responses to NRAs; however, it is requested that proposals conform to the guidelines in these instructions. NASA may accept proposals without discussion; hence, proposals should initially be as complete as possible and be submitted on the proposers' most favorable terms.

b. In order to be considered responsive, a submission must, at a minimum, present a specific project within the areas delineated by the NRA; contain sufficient technical and cost information to permit a meaningful evaluation; be signed by an official authorized to legally bind the submitting organization; not merely offer to perform standard services or to just provide computer facilities or services; and not significantly duplicate a more specific current or pending NASA solicitation.

6. NRA-Specific Items

a. Several proposal submission items appear in the NRA itself. These include: the unique NRA identifier; when to submit proposals; where to send proposals; number of copies required; and sources for more information.

b. Items included in these instructions may be supplemented by the NRA.

7. Proposal Contents

a. The following information is needed in all proposals in order to permit consideration in an objective manner. NRAs will generally specify topics for which additional information or greater detail is desirable. Each proposal copy shall contain all submitted material, including a copy of the transmittal letter if it contains substantive information.

b. **Transmittal Letter or Prefatory Material.**

(1) The legal name and address of the organization and specific division or campus identification if part of a larger organization;

(2) A brief, scientifically valid project title intelligible to a scientifically literate reader and suitable for use in the public press;

(3) Type of organization: e.g., profit, nonprofit, educational, small business, minority, women-owned, etc.;

(4) Name and telephone number of the Principal Investigator and business personnel who may be contacted during evaluation or negotiation;

(5) Identification of other organizations that are currently evaluating a proposal for the same efforts;

(6) Identification of the NRA, by number and title, to which the proposal is responding;

(7) Dollar amount requested , desired starting date, and duration of project;

(8) Date of submission; and

(9) Signature of a responsible official or authorized representative of the organization, or any other person authorized to legally bind the organization (unless the signature appears on the proposal itself).

c. **Restriction on Use and Disclosure of Proposal Information**

Information contained in proposals is used for evaluation purposes only. Offerors or quoters should, in order to maximize protection of trade secrets or other information that is confidential or privileged, place the following notice on the title page of the proposal and specify the information subject to the notice by inserting appropriate identification, such as page numbers, in the notice. In any event, information contained in proposals will be protected to the extent permitted by law, but NASA assumes no liability for use and disclosure of information not made subject to the notice.

NOTICE --- Restriction on Use and Disclosureof Proposal Information

The information (data) contained in [insert page numbers or other identification] of this proposal constitutes a trade secret and/or information that is commercial or financial and confidential or privileged. It is furnished to the Government in confidence with the understanding that it will not, without permission of the offeror, be used or disclosed other than for evaluation purposes; provided, however, that in the event a contract (or other agreement) is awarded on the basis of this proposal the Government shall have the right to use and disclose this information (data) to the extent provided in the contract (or other agreement). This restriction does not limit the Government's right to use or disclose this information (data) if obtained from another source without restriction.

d. **Abstract**

Include a concise (200-300 word if not otherwise specified in the NRA) abstract describing the objective and the method of approach.

e. **Project Description**

(1) The main body of the proposal shall be a detailed statement of the work to be undertaken and should include objectives and expected significance; relation to the present state of knowledge; and relation to previous work done on the project and to related work in progress elsewhere. The statement should outline the plan of work, including the broad design of experiments to be undertaken and a description of experimental methods and procedures. The project description should address the evaluation factors in these instructions and any specific factors in the NRA. Any substantial collaboration with individuals not referred to in the budget or use of consultants should be described. Subcontracting significant portions of a research project is discouraged.

(2) When it is expected that the effort will require more than one year for completion, the proposal should cover the complete project to the extent that it can be reasonably anticipated. Principal emphasis should, of course, be on the first year of work, and the description should distinguish clearly between the first year's work and work planned for subsequent years.

f. **Management Approach**

For large or complex efforts involving interactions among numerous individuals or other organizations, plans for distribution of responsibilities and arrangements for ensuring a coordinated effort should be described. Intensive working relations with NASA field centers that are not logical inclusions elsewhere in the proposal should be described.

g. **Personnel**

The Principal Investigator is responsible for supervision of the work and participates in the conduct of the research regardless of whether or not compensated under the award. A short biographical sketch of the Principal Investigator, a list of principal publications and any exceptional qualifications should be included. Omit social security number and other personal items which do not merit consideration in evaluation of the proposal. Give similar biographical information on other senior professional personnel who will be directly associated with the project. Give the names and titles of any other scientists and technical personnel associated substantially with the project in an advisory capacity. Universities should list the approximate number of students or other assistants, together with information as to their level of academic attainment. Any special industry- university cooperative arrangements should be described.

h. **Facilities and Equipment**

(1) Describe available facilities and major items of equipment especially adapted or suited to the proposed project, and any additional major equipment that will be required. Identify any Government-owned facilities, industrial plant equipment, or special tooling that are proposed for use.

(2) Before requesting a major item of capital equipment, the proposer should determine if sharing or loan of equipment already within the organization is a feasible alternative. Where such arrangements cannot be made, the proposal should so state. The need for items that typically can be used for research and non-research purposes should be explained.

i. **Proposed Costs**

(1) Proposals should contain cost and technical parts in one volume: do not use separate "confidential" salary pages. As applicable, include separate cost estimates for salaries and wages; fringe benefits; equipment; expendable materials and supplies; services; domestic and foreign travel; ADP expenses; publication or page charges; consultants; subcontracts; other miscellaneous identifiable direct costs; and indirect costs. List salaries and wages in appropriate organizational categories (e.g., Principal Investigator, other scientific and engineering professionals, graduate students, research

assistants, and technicians and other non-professional personnel). Estimate all manpower data in terms of man-months or fractions of full-time.

(2) Explanatory notes should accompany the cost proposal to provide identification and estimated cost of major capital equipment items to be acquired; purpose and estimated number and lengths of trips planned; basis for indirect cost computation (including date of most recent negotiation and cognizant agency); and clarification of other items in the cost proposal that are not self- evident. List estimated expenses as yearly requirements by major work phases. (Standard Form 1411 may be used).

(3) Allowable costs are governed by FAR Part 31 and the NASA FAR Supplement Part 18-31 (and OMB Circulars A-21 for educational institutions and A-122 for nonprofit organizations).

j. **Security**

Proposals should not contain security classified material. If the research requires access to or may generate security classified information, the submitter will be required to comply with Government security regulations.

k. **Current Support**

For other current projects being conducted by the Principal Investigator, provide title of project, sponsoring agency, and ending date.

l. **Special Matters**

(1) Include any required statements of environmental impact of the research, human subject or animal care provisions, conflict of interest, or on such other topics as may be required by the nature of the effort and current statutes, executive orders, or other current Government-wide guidelines.

(2) Proposers should include a brief description of the organization, its facilities, and previous work experience in the field of the proposal. Identify the cognizant Government audit agency, inspection agency, and administrative contracting officer, when applicable.

8. Renewal Proposals

a. Renewal proposals for existing awards will be considered in the same manner as proposals for new endeavors. A renewal proposal should not repeat all of the information that was in the original proposal. The renewal proposal should refer to its predecessor, update the parts that are no longer current, and indicate what elements of the research are expected to be covered during the period for which support is desired. A description of any significant findings since the most recent progress report should be included. The renewal proposal should treat, in reasonable detail, the plans for the next period, contain a cost estimate, and otherwise adhere to these instructions.

b. NASA may renew an effort either through amendment of an existing contract or by a new award.

9. Length

Unless otherwise specified in the NRA, effort should be made to keep proposals as brief as possible, concentrating on substantive material. Few proposals need exceed 15-20 pages. Necessary detailed information, such as reprints, should be included as attachments. A complete set of attachments is necessary for each copy of the proposal. As proposals are not returned, avoid use of "one-of-a-kind" attachments: their availability may be mentioned in the proposal.

10. Joint Proposals

a. Where multiple organizations are involved, the proposal may be submitted by only one of them. It should clearly describe the role to be played by the other organizations and indicate the legal and managerial arrangements contemplated. In other instances, simultaneous submission of related proposals from each organization might be appropriate, in which case parallel awards would be made.

b. Where a project of a cooperative nature with NASA is contemplated, describe the contributions expected from any participating NASA investigator and agency facilities or equipment which may be required. The proposal must be confined only to that which the proposing organization can commit itself. "Joint" proposals which specify the internal arrangements NASA will actually make are not acceptable as a means of establishing an agency commitment.

11. Late Proposals

A proposal or modification received after the date or dates specified in an NRA may be considered if the selecting official deems it to offer NASA a significant technical advantage or cost reduction.

12. Withdrawal

Proposals may be withdrawn by the proposer at any time. Offerors are requested to notify NASA if the proposal is funded by another organization or of other changed circumstances which dictate termination of evaluation.

13. Evaluation Factors

a. Unless otherwise specified in the NRA, the principal elements (of approximately equal weight) considered in evaluating a proposal are its relevance to NASA's objectives, intrinsic merit, and cost.

b. Evaluation of a proposal's relevance to NASA's objectives includes the consideration of the potential contribution of the effort to NASA's mission.

c. Evaluation of its intrinsic merit includes the consideration of the following factors, none of which is more important than any other:

(1) Overall scientific or technical merit of the proposal or unique and innovative methods, approaches, or concepts demonstrated by the proposal.

(2) Offeror's capabilities, related experience, facilities, techniques, or unique combinations of these which are integral factors for achieving the proposal objectives.

(3) The qualifications, capabilities, and experience of the proposed Principal Investigator, team leader, or key personnel critical in achieving the proposal objectives.

(4) Overall standing among similar proposals and/or evaluation against the state-of-the-art.

d. Evaluation of the cost of a proposed effort includes the realism and reasonableness of the proposed cost and the relationship of the proposed cost and available funds.

14. Evaluation Techniques

Selection decisions will be made following peer and/or scientific review of the proposals.

Several evaluation techniques are regularly used within NASA. In all cases proposals are subject to scientific review by discipline specialists in the area of the proposal. Some proposals are reviewed entirely in-house, others are evaluated by a combination of in-house and selected external reviewers, while yet others are subject to the full external peer review technique (with due regard for conflict-of- interest and protection of proposal information), such as by mail or through assembled panels. The final decisions are made by a NASA selecting official. A proposal which is scientifically and programmatically meritorious, but not selected for award during its initial review, may be included in subsequent reviews unless the proposer requests otherwise.

15. Selection for Award

a. When a proposal is not selected for award, and the proposer has indicated that the proposal is not to be held over for subsequent reviews, the proposer will be notified. NASA will explain generally why the proposal was not selected. Proposers desiring additional information may contact the selecting official who will arrange a debriefing.

b. When a proposal is selected for award, negotiation and award will be handled by the procurement office in the funding installation. The proposal is used as the basis for negotiation. The contracting officer may request certain business data and may forward a model contract and other information which will be of use during the contract negotiation.

16. Cancellation of NRA

NASA reserves the right to make no awards under this NRA and to cancel this NRA. NASA assumes no liability for canceling the NRA or for anyone's failure to receive actual notice of cancellation. Cancellation may be followed by issuance and synopsis of a revised NRA, since amendment of an NRA is normally not permitted.

Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004

Prospects for Breakthrough Propulsion from Physics

(Available as NASA TM-2004-213082)

May-2004

Marc G. Millis

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Abstract

"Space drives," "Warp drives," and "Wormholes:" these concepts may sound like science fiction, but they are being written about in reputable journals. To assess the implications of these emerging prospects for future spaceflight, NASA supported the Breakthrough Propulsion Physics Project from 1996 through 2002. This Project has three grand challenges: (1) Discover propulsion that eliminates the need for propellant; (2) Discover methods to achieve hyper-fast travel; and (3) Discover breakthrough methods to power spacecraft. Because these challenges are presumably far from fruition, and perhaps even impossible, a special emphasis is placed on selecting incremental and affordable research that addresses the critical issues behind these challenges. Of 16 incremental research tasks completed by the Project and from other sponsors, about a third were found not to be viable, a quarter have clear opportunities for sequels, and the rest remain unresolved.

1. Introduction

New theories and phenomena have emerged in recent scientific literature that have reawakened consideration that propulsion breakthroughs may become achievable - the kind of breakthroughs that could make human voyages to other star systems possible. This includes literature about warp drives, wormholes, quantum tunneling, vacuum fluctuation energy, and the coupling of gravity and electromagnetism. This emerging science, combined with the realization that rockets are fundamentally inadequate for interstellar exploration, led NASA to establish the "Breakthrough Propulsion Physics (BPP)" Project in 1996 [1].

This paper summarizes the methods and findings of this Project as well as findings from other parallel efforts. The methods are described to reflect the special management challenges and corresponding mitigation strategies for dealing with such visionary topics in a constructive manner. Projections of future research are also offered.

2. Methods

As the name implies, the BPP Project is specifically looking for propulsion *breakthroughs* from *physics*. It is **not** looking for further *technological* refinements of existing methods. Such refinements are explored in other NASA projects. Instead, this Project looks beyond the known methods, searching for further advances from emerging *science* from which genuinely new technology can develop - technology to surpass the limits of existing methods.

2.1. Technical Challenges

The first step toward solving a problem is to define the problem. The following three *Grand Challenges* represent the critical discoveries needed to revolutionize spaceflight and enable interstellar missions:

> **Challenge 1 - MASS:** Discover new propulsion methods that eliminate or dramatically reduce the need for propellant. This implies discovering fundamentally new ways to create motion, presumably by interacting with the properties of space, or possibly by manipulating gravitational or inertial forces.
> **Challenge 2 - SPEED:** Discover how to dramatically reduce transit times. This implies discovering a means to move a vehicle near the light-speed limit *through* space, or by manipulating spacetime to circumvent the light-speed limit.
>
> **Challenge 3 - ENERGY:** Discover fundamentally new modes of onboard energy production to power these propulsion devices. This third goal is included since the first two breakthroughs might require breakthroughs in energy generation, and since the physics underlying the propulsion goals is closely linked to energy physics.

2.2. Special Challenges and Mitigations

The combination of high-payoff prospects plus the speculative nature of the edge of knowledge evokes special management challenges. To produce credible progress under these conditions, the BPP Project employs the following operating strategies:

- **Reliability:** Success is defined as acquiring reliable knowledge, rather than as achieving a breakthrough. This emphasis steers publications toward credible progress and away from sensationalistic claims.
- **Immediacy:** Research is focused on the immediate unknowns, make-or-break issues, or curious effects.
- **Iterated:** Overall progress is achieved by repeating a cycle of short-term, incremental tasks.
- **Diversified:** Multiple, divergent research topics are explored simultaneously.
- **Measured:** Progress is tracked using a combination of the scientific method and the applicability of the research to the Project's goals.
- **Impartial:** Reviewers judge credibility and relevance, but are not asked to predict the

feasibility of research approaches.
- **Empirical:** Preference is given to experiments and empirical observations over purely analytical studies.
- **Published:** Results are published, regardless of outcome. Null results are also valuable progress.

Given the kind of fundamental investigations sought by this Project, it is difficult to reliably determine technical feasibility during a proposal review. Such an assessment would constitute a full research task itself. Typically, when confronted with the kind of unfamiliar ideas related to this endeavor, many reviewers will reflexively assume that the new idea will not work. To prevent premature dismissal, proposal reviewers are asked to judge if the work is leading to a result that other researchers will consider as a reliable conclusion on which to base future investigations. This includes seeking tasks that can demonstrate that certain research approaches are not feasible. This posture of judging credibility, rather than pre-judging correctness, is one of the ways that the BPP Project is open to visionary concepts while still sustaining credibility.

3. Findings

In addition to the 8 tasks supported through the BPP Project, at least 8 additional tasks were supported by others, and several related research efforts continue. Of the 16 specific tasks reported and summarized here, 6 were found not to be viable, 6 remain unresolved or have debatable findings, and 4 have clear opportunities for sequels.

It should be stressed, however, that even interim positive results do not imply that a breakthrough is inevitable. Often the opportunity for sequels is more a reflection of the embryonic state of the research. Reciprocally, a dead-end conclusion on a given task does not imply that the broader related topics are equally defunct. Both the null and positive results should only be interpreted within the context of the immediate research task, and not generalized beyond. This is consistent with the operating strategy to focus on the immediate stage of the research, and the strategy to put a higher priority on the reliability of the information rather than on producing broad-sweeping claims.

It should also be stressed that these task summaries do not reflect a comprehensive list of research options. It is expected that new concepts will continue to emerge in such an embryonic field.

3.1. BPP Sponsored Research

The NASA BPP Project sponsored 5 tasks through competitive selection, 2 in-house tasks, and 1 minor grant. From this work, 13 peer-reviewed journal articles resulted [1-13]. Summaries of each of the 8 tasks are offered below.

3.1.1. Define Space Drive Strategy. "Space drive" is a general term to encompass the ambition of the first BPP Challenge: propulsion without propellant. To identify the unresolved issues and research paths toward creating a space drive, this in-house task conceived and assessed 7 hypothetical space drives. The two largest issues facing this ambition are to first find a way for a vehicle to induce *external, net* forces on itself, and secondly, to satisfy conservation of momentum in the process. Several avenues for research remain, including: (1) investigate space from the perspective of new sources of reaction mass, (2) revisit Mach's Principle to consider coupling to surrounding mass via inertial frames, and (3) investigate the coupling between gravity, inertia, and controllable electromagnetic phenomena [2]. These are very broad and open areas where a variety of research sequels could emerge.

3.1.2. Test Schlicher Thruster. In-house experiments were performed to test claims that a specially terminated coax, as reported by Rex Schlicher [14], could create more thrust than attributable to photon radiation pressure. Tests observed no such thrust [15].

3.1.3. Assess Deep Dirac Energy. Theories based on the work of Dirac assert that additional energy levels and energy transitions might be possible in atomic structures [16]. A theoretical assessment, supported via a grant to Robert Deck (Univ. Toledo, Grant NAG 3-2421), found that several of the predicted energy transitions are not possible. Other unexplored possibilities remain. This topic is not fully resolved. Findings have been submitted for journal publication.

3.1.4. Cavendish Test of Superconductor Claims. As a lower-cost alternative to a full replication of the Podkletnov "gravity shielding" claim [17], Cavendish balance experiments were performed using superconducting materials and radio frequency (RF) radiation according to related theories. It was found that the RF radiation coupled too strongly to supporting instrumentation and prevented any discernable results [18]. No sequels to this approach are expected.

Other groups sponsored full replications of the Podkletnov configuration, and their findings are presented in section 3.2.3.

3.1.5. Test Woodward Transient Inertia. Experiments and theories published by James Woodward claim that transient changes to inertia can be induced by electromagnetic means [19, 20], and a patent exists on how this can be used for propulsion [21]. Independent verification experiments, using techniques less prone to spurious effects, were sponsored. Unfortunately, when subsequent publications by Woodward indicated that the effect was much smaller than originally reported [22], the independent test program had to be changed. The revised experiments were unable to resolve any discernable effect with the available resources [23]. Woodward continues with experiments and publications [24], and has begun addressing the theoretical issues identified during this independent assessment. This transient inertia approach is considered unresolved.

3.1.6. Test EM Torsion Theory. Theories using a torsion analogy to the coupling between electro-magnetism and spacetime [25] indicate the possibility of asymmetric interactions that might be of use, at least in principle, for propulsion [26]. Experiments were sponsored to test a related prediction of the theory, but the results were null. Further analysis indicates that the experiments missed a critical characteristic to correctly resolve the issue [27]. This approach is considered unresolved.

3.1.7. Explore Superluminal Tunneling. A pre-requisite to faster-than-light *travel* is to prove faster-than-light *information* transfer. The phenomenon of quantum tunneling, where signals *appear* to pass through barriers at superluminal speed, is often cited as such empirical evidence. Experimental and theoretical work was sponsored to explore the special case where energy is added to the barrier (tunnel). Even in this case it was found that the information transfer rate is still only *apparently* superluminal, with no causality violations. Although the leading edge of the signal does make it through the barrier faster, the entire signal is still light-speed limited [3-5]. Although other quantum phenomena still suggest faster-than-light connections (e.g. quantum entanglement), the venue of quantum tunneling does not appear to be a viable approach for exploring faster-than-light propulsion.

3.1.8. Explore Vacuum Energy. Quantum vacuum energy, also called zero point energy (ZPE), is a relatively new and not fully understood phenomenon. In simple terms, the *uncertainty principle* from quantum mechanics indicates that it is not possible to achieve an absolute zero energy state. This includes the electromagnetic energy state of the space vacuum [28]. It has been shown analytically, and later experimentally, that this vacuum energy can squeeze parallel plates together [29]. This "Casimir effect" is only appreciable at very small dimensions (microns). Nonetheless, it is evidence that space contains something that might be useful. The possibility of extracting this energy has also been studied. In principle, and without violating thermodynamic laws, it is possible to convert minor amounts of quantum vacuum energy [30, 31].

The BPP Project sponsored experimental and theoretical work to further explore the tangibility of this phenomenon. New analytical and experimental tools were developed to explore this phenomenon using MicroElectroMechanical (MEM) rectangular Casimir cavities [6-12]. It was even shown that, in principal, it is possible to create net propulsive forces by interacting with this energy, even thought the forces are impractically small at this stage [13]. Regardless of these immediate impracticalities, however, the quantum vacuum does offer an experimental venue through which to further study the very structure of space itself. Continued research on this phenomenon and through these techniques is expected.

3.2. Research Sponsored by Others

While the NASA BPP Project scouted for multiple, divergent research approaches using competitive solicitations, several other organizations focused on individual tasks. Several examples of such work are presented next.

3.2.1. Slepian-Drive. Funded through a Con-gressional earmark, the West Virginia Institute for Scientific Research (ISR) is conducting experimental and theoretical assessments of the propulsive implications of electromagnetic momentum in dielectric media. The equations that describe electromagnetic momentum in vacuum are well established (photon radiation pressure), but there is still scientific debate concerning momentum within dielectric media, specifically the "Abraham-Minkowski controversy." More than one concept exists for how this might apply to propulsion and several terms are used to refer to this topic, such as "Slepian-Drive," "Heaviside Force," "Electromagnetic Stress-Tensor Propulsion," and the "Feynman Disk Paradox." To date, ISR has submitted a tutorial paper on the phenomenon to a journal, and has produced a conference paper on interim experimental findings [32]. An independent assessment by the Air Force Academy concluded that no *net* propulsive forces are expected with this approach [33].

Separate from the ISR work, independent research published by Dr. Hector Brito details a propulsive device along with experimental data [34]. The signal levels are not sufficiently above the noise as to be conclusive proof of a propulsive effect.

While not specifically related to propulsion, a recent journal article assessed the Abraham-Minkowski controversy from a quantum physics perspective, suggesting it might be useful for micro-fluidics or other applications [35].

In all of these approaches, the anticipated forces are relatively small, and critical issues remain unresolved. In particular, the conversion of *oscillatory* forces to *net* forces (Slepian-Drive) remains questionable, and the issue of generating *external* forces from different *internal* momenta remains questionable. Even if not proven suitable for propulsion, these approaches provide empirical tools for further exploring the Abraham-Minkowski controversy of electromagnetic momentum. This topic is considered unresolved.

3.2.2. Cosmological Consequences of Vacuum Energy. Theoretical work, sponsored by NASA Headquarters from 1996 to 1999 [Contract NASW-5050], examined the role played by quantum vacuum energy on astrophysical observations. Of the 5 journal articles that resulted [36-40], the last two pertain most to breakthrough propulsion. These made the controversial assertion that inertia might be an electromagnetic drag force that occurs during accelerated motion through vacuum energy. This led to speculation that it might become possible to alter inertial properties through some electromagnetic means [41]. Work toward this perspective continues, but through private sponsorship, described in section 3.3.4.

3.2.3. Tests of Podkletnov Claim. In 1992, a controversial claim of a "gravity shielding" effect was published by E. Podkletnov based on work done at Finland's Tampere Institute [17]. Regrettably, the article was not fully forthcoming with all of the experimental methods and jumped to the conclusion that a gravity shield effect was responsible for the anomalous weight reductions observed over spinning superconductors. Although others dismissed this effect on the grounds that it violates conservation of energy [42], this dismissal itself did not take into account that the claimed effect consumes energy.

From 1995 to 2002, NASA Marshall Space Flight Center (MSFC) attempted a full experimental replication of the Podkletnov configuration [43], but was not able to complete the test hardware with the available resources.

A privately funded replication of the Podkletnov configuration was completed by Hathaway, Cleveland and Bao, and the results published in 2003 [44]. This work "found no evidence of a gravity-like force to the limits of the apparatus sensitivity," where the sensitivity was "50 times better than that available to Podkletnov." Therefore, this rotating, RF-pumped superconductor approach is considered non-viable.

3.2.4. Podkletnov Force-Beam Claims. Through undisclosed sponsorship, Podkletnov produced a new claim - that of creating a force-beam using high-voltage discharges near superconductors. His results, posted on an Internet physics archive [45], claim to impart between 4×10^{-4} to 23×10^{-4} Joules of mechanical energy to a distant 18.5-gram pendulum. Like his prior "gravity shielding" claims, these experiments would be difficult and costly to duplicate, and remain unsubstantiated by reliable independent sources.

3.2.5. Gravity Modification Study. The European Space Agency (ESA) sponsored a study on the prospects of gravity control for propulsion [46]. The following research avenues were identified:

- Search for violations of the Equivalence Principle through ongoing in-space experiments.
- Resolve the anomalous trajectories of *Pioneer 10/11*, *Galileo*, and *Ulysses* [47], via a "Sputnik-5" probe.
- Experimentally explore gravitomagnetic fields in quantum materials [48].

Opportunities for continued research clearly exist on any of these options.

3.2.6. Anomalous Heat Effect. Although not covered within the confines of breakthrough propulsion research, the controversial topic of "cold fusion" is often encountered when addressing the edge of energy conversion physics. It is in the spirit of completeness that the findings of a decade of research by the Naval Research Labs (NRL) are mentioned here. In their 119-page report [49], various experiments with conflicting results are described. The *Forward* to this compilation states: "It is time that this phenomenon be investigated so that we can reap whatever benefits accrue from additional scientific understanding." This report serves as a broad overview of the variety of techniques and issues encountered. This remains a controversial topic.

3.2.7. Biefeld-Brown and Variants. In 1928 a device was patented for creating thrust using high-voltage capacitors [50]. Since then, a wide variety of variants of this "Biefeld-Brown" effect, such as "Lifters" and "Asymmetrical Capacitors" have claimed that such devices operate on an "electrostatic antigravity" or "electrogravitic" effect. One of the most recent variants was patented by NASA-MSFC [51]. To date, all rigorous experimental tests indicate that the observed thrust is attributable to ion wind [52-54].

Vacuum tests currently underway, sponsored through an additional Congressional earmark to the West Virginia Institute for Scientific Research, also indicate that this effect is not indicative of new propulsion physics. These tests are now assessing the more conventional performance of such devices [55].

These "Biefeld-Brown," "Lifter" and "Asymmetrical Capacitor Thrusters" are not viable candidates for breakthrough physics propulsion.

3.3. Ongoing Activities

In addition to the discrete research tasks previously described, there are a few continuing areas of research.

3.3.1. Metric Engineering. As a consequence of Einstein's General Relativity, the notion of warping space to circumvent the light-speed limit is a growing topic in scientific literature [56-65]. In basic terms, if one cannot break the light-speed limit *through* space, then *alter* space. Two prominent approaches are the *warp drive* and the *wormhole*. The warp drive concept involves moving a bubble of spacetime, which carries a vehicle inside [61]. A wormhole, on the other hand, is a shortcut through spacetime created by extreme spacetime warping [57, 59]. Enormous technical hurdles face these concepts. In particular, they require enormous quantities of "negative energy" (equivalent mass of planets or suns), and evoke time-travel paradoxes ("closed-time-like curves").

In 1994, NASA sponsored a small workshop to assess these prospects [66]. The results fed into the BPP Project and led to an article defining the visual signature of a wormhole as a guide for astronomical searchers for black-hole related phenomena [67].

Recently, the term "metric engineering" [65] has emerged at aerospace conferences to represent such space-warping propulsion concepts. The origin of this term is unknown.

Given the magnitude of energy requirements to create perceptible effects, it is unlikely that experimental work will be forthcoming in the near future. Even though these theoretical concepts are extremely unlikely to be engineered, they are at least useful as teaching tools to more thoroughly explore the intricacies of Einstein's General Relativity. It is likely that theoretical work will continue to emerge on this topic.

3.3.2. High Frequency Gravitational Waves. Fundamentally, gravitational waves are perturbations in spacetime caused by violent accelerations of large masses, such as collisions of black holes. Ongoing research focuses on low frequency gravitational waves (<1000-Hz) using large interferometers, such as the Laser Interferometer Gravitational Wave Observatory (LIGO) detector whose arms are 4-km (2.5-mi) in length [68].

In contrast, alternative approaches have been suggested to detect High Frequency Gravitational

Waves (HFGW). A variety of experimental approaches (introduced at a 2003 workshop) were summarized in a recent conference paper [69]. These detection concepts typically involved desktop size devices, with implications for communication, imaging, and fundamental physics research. Some of the key issues governing the viability of such devices include the energy transfer mechanisms and the low efficiencies predicted. This is an embryonic area where a wide variety of research remains to be addressed.

3.3.3. Project Greenglow, British Aerospace Sys. Similar to the NASA BPP Project, British Aerospace Systems, Inc. sponsored a modest project to look at a variety of breakthrough propulsion appraoches. Headed by Dr. Ron Evans, incremental research tasks were supported that included assessments of Podkletnov's gravity shield claims (null findings) [70], experimental and theoretical works on microwave thrusters [71], and various theoretical works on gravitation [72-76], vacuum forces [77], and "what-if" assessments [78]. It is not known if, or at what level, this project will continue.

3.3.4. Private Quantum Vacuum Research. Since 1990, the small Advanced Studies Institute, in Austin Texas, has been supported through private funds to test claims of new energy devices and related physics [31, 41, 79-82]. Their most relevant publications for BPP deal with the connection between the quantum vacuum and the definitions of inertia and gravity [41, 79, 81]. Like the NASA-HQ sponsored task previously mentioned, these make the controversial assertion that inertia is merely an electromagnetic drag force against the quantum vacuum fluctuations [81] and closely related, that gravity is a consequence of the quantum vacuum fluctuations [79].

Beginning in 2000, the small California Institute for Physics and Astrophysics (CIPA) has also been privately supported to conduct research on quantum vacuum physics. Their work also explores the controversial assertion that inertia is an electromagnetic drag force, in addition to exploring other issues [83-88].

4. Future Prospects

The search for new, breakthrough propulsion methods from physics is an embryonic field encompassing many differing approaches and challenges. In addition to the research already described, there are many more approaches published in the literature and presented at aerospace conferences.

At this stage it is still too early to predict which, if any, of the approaches might lead to a successful breakthrough. Objectively, the desired breakthroughs might be impossible to achieve. Reciprocally, history has shown that breakthroughs tend to take the pessimists by surprise.

A key challenge, in addition to the daunting physics, is dealing with such visionary topics in a credible, impartial, and productive manner. When considering future prospects, this management challenge must be taken into account to ensure genuine, reliable progress. The methods used by the NASA Breakthrough Propulsion Physics Project are offered as a benchmark.

4.1. Research Support

Much of the past research has been conducted in the form of individual discretionary efforts, scattered across various government, academic, and private organizations. This practice of isolated efforts is likely to continue, but there is no way to gauge the level of effort or the fidelity of this research. The more rigorous and open progress will continue to appear in the peer-reviewed journals, however.

Regarding the NASA BPP Project, future funding is uncertain. NASA is now assessing how to respond to the President's priorities on Moon and Mars exploration. It is not clear if there is a place for propulsion physics research within these priorities. Previously, the President's Aerospace Commission recommended supporting such visionary work. Quoting from the Commission's report [89]: "In the longer-term, breakthrough energy sources that go beyond our current understanding of physical laws... must be credibly investigated in order for us to practically pursue human exploration of the solar system and beyond. These energy sources should be the topic of a focused, basic research effort." If NASA sponsorship resumes, it might appear under the revised title: "Fundamental Propulsion Physics."

Regarding the privately sponsored projects, such as the British Aerospace Systems' Project Greenglow and the institutes that examine quantum vacuum physics, future funding details are unknown. Recently, an *Aviation Week and Space Technology* article states: "At least one large aerospace company is embarking on ZPE [quantum vacuum] research in response to a Defense Dept. request." [90] Given the private and protected nature of such sponsorship, it is not known to what extent these results will be disseminated.

4.2. Research Options

The few research approaches that have been summarized here mostly started from the point of view of seeking propulsion breakthroughs, and went on to confront the immediate issues and unknowns that these goals evoked. Many of these approaches await resolution and many sequels to these approaches remain unexplored.

In addition to this propulsion-initiated perspective, an alternative approach is to examine the various *disciplines* of physics, and then ask how their emerging insights, and anomalies, might be relevant to propulsion. In the first step of the scientific method, where one clearly formulates the problem to guide the search for knowledge, the propulsion challenge is different than the broader scientific objective to fully understand nature. This change in focus presents a different perspective, and therein provides an opportunity to possibly discover what the more general approach might overlook.

Both of these perspectives, studying the physics required for propulsion, and considering the propulsive implications of emerging physics, provide many options for future research.

5. Concluding Remarks

A wide variety of small research tasks explored the physics issues associated with seeking breakthrough propulsion. Although many approaches were found to be dead-ends, more remain unresolved and further possibilities remain unexplored. At this stage, the work is embryonic and faces challenges typical of any new, emerging area.

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Aerospace Commission recommends funding basic research toward breakthrough capabilities

On November 18, 2002, The Commission on the Future of the U.S. Aerospace Industry released its final report. Quoting from their release: "The 12 members of the Commission represent a broad cross section of the stakeholders responsible for the health of the industry and whose expertise represents the breadth and depth of aerospace issues. Drawing on their extensive experience, and on the hundreds of briefings and public testimony, the Commission issued nine recommendations that provide guidance to the nation's leaders on the future of the U.S. aerospace industry. Recommendations and findings are presented in the areas of a national aerospace vision, air transportation, space, national security, government reform, global markets, business, workforce, and research and development."

Of particular interest to the Breakthrough Propulsion Physics Project are the following quotes:

Quoting from the Executive summary:

> "Achieve Breakthroughs in Propulsion and Space Power."

Quoting from Recommendation #9:

> "The Commission recommends that the federal government significantly increase its investment in basic aerospace research, which enhances U.S. national security, enables breakthrough capabilities, and fosters an efficient, secure, and safe aerospace transportation system."

From page 9-5:

> "New propulsion concepts based on breakthrough energy sources, ... could result in a new propulsion paradigm that will revolutionize space transportation."

From page 9-6:

> "In the longer-term, breakthrough energy sources that go **beyond our current understanding of physical laws**... **must be credibly investigated** in order for us to practically pursue human exploration of the solar system and beyond. These energy sources should be the topic of a focused basic research effort." [bold emphasis by Millis]

From Figure 9-3:

Research Areas:

Breakthrough Energy Sources:

Hydrogen
Nuclear (fusion) / Plasma
Anti-matter, zero-point

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Last update: May 13, 2004

TD15-PLN-015

John H. Glenn Research Center Baseline

21000 Brookpark Rd., Cleveland OH 44135 December 4, 2000

(Note: Formatting errors may have occurred in this document in conversion to htm)

Project Plan

for

Breakthrough Propulsion Physics (BPP)

Space Transportation Research

Investment Area

ADVANCED SPACE TRANSPORTATION PROGRAM OFFICE (ASTP)

SPACE TRANSPORTATION PROJECT OFFICE

CHECK THE MASTER LIST-VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

BREAKTHROUGH PROPULSION PHYSICS PROJECT PLAN

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BREAKTHROUGH PROPULSION PHYSICS PROJECT PLAN

Signature Page

Prepared by:

Signature on File, dated Dec. 5, 2000

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Space Transportation Project Office Manager, NASA Glenn Research Center

List of ACRONYMS

ASTAC	Aero-Space Technology Advisory Committee
ASTP	Advanced Space Transportation Program
AT	Aerospace Technology
BPP	Breakthrough Propulsion Physics
COTR	Contracting Officer Technical Representative
DOD	Department of Defense
DOE	Department of Energy
EOARD	USAF European Office of Aerospace Research and Development
FY	Fiscal Year
GRC	Glenn Research Center
IAR	Independent Annual Review
ITAR	International Traffic In Arms Regulations
JPC	Point Propulsion Conference
JPL	Jet Propulsion Laboratory
MOU	Memorandum of Understanding
MSFC	Marshall Space Flight Center
NAR	Non Advocate Review
NASA	National Aeronautics and Space Administration
NIAC	NASA Institute for Advanced Concepts
NPD	NASA Program Directive
NPG	NASA Procedures and Guidelines
NRA	NASA Research Announcement
NSSTC	National Space Science and Technology Center
OAI	Ohio Aerospace Institute
PI	Principal Investigator
PLT	Program Leadership Team
PMC	Project Management Council
POC	Point of Contact
POP	Program Operating Plan
SBIR	Small Business Innovative Research
SM	Scientific Method
STPO	Space Transportation Project Office (at GRC)
TBD	To Be Determined

TRL	Technology Readiness levels
USAF	United States Air Force
WBS	Work Breakdown Structure

Foreword

This Project Plan describes the planning and objectives for implementing the NASA Breakthrough Propulsion Physics Project. This plan has been prepared in accordance with the *NASA Program and Project Management Processes and Requirements*, NPG 7120.5A, and is consistent with the *NASA Strategic Management Handbook* and *NASA Program/Project Management*, NPD 7120.4.

I. INTRODUCTION

The Breakthrough Propulsion Physics (BPP) project, which is managed by the Glenn Research Center (GRC), is a project under the Advanced Space Transportation Program (ASTP) that is managed by the Marshall Space Flight Center (MSFC).

The ASTP is a comprehensive program for advancing space propulsion and spans the near-term technology improvements all the way through seeking the breakthroughs that could revolutionize space travel and enable interstellar voyages. The Breakthrough Propulsion Physics Project is at the most visionary end of this spectrum of activities. With respect to the 2001 Strategic Implementation Plan of the NASA Aerospace Technology (AT) Enterprise, this project supports AT Goal 2 (Advance Space Transportation) and Goal 3 (Pioneer Technology Innovation); specifically AT Objectives 7 through 10 (Mission Affordability, Mission Reach, Engineering Innovation, and Technology Innovation).

As its name suggests, the Breakthrough Propulsion Physics Project is specifically looking for propulsion *breakthroughs* from *physics*. It is not looking for further *technological refinements* of existing methods. Such refinements are being explored in other projects under the ASTP. Instead, this project looks beyond existing methods, searching for further advances in science from which genuinely new technology can emerge - technology to surpass the limits of existing methods. Topics of interest include experiments and theories regarding the coupling of gravity and electromagnetism, vacuum fluctuation energy, warp drives and wormholes, and superluminal quantum effects. Because these propulsion goals are presumably far from fruition, a special emphasis of the project is to identify and support affordable, near-term, and credible research that will make incremental progress toward these propulsion goals.

The need for a Project with a focus on emerging physics was recognized from the fact that rocket physics – no matter how advanced in technological embodiment – is fundamentally inadequate for interstellar distances. The only way to surpass these limits is if new, better propulsion physics can be discovered. Furthermore, a focused effort is needed rather than relying solely on the general progression of science. In the first step of the scientific method, where one clearly formulates the problem to guide the search for knowledge, this NASA Project has a unique problem: how to propel spacecraft as far and as fast as possible and with the least amount of effort. Such a focus will present different lines of inquiry than general physics alone. By asking different questions and looking along a different path, this program provides the focus to make discoveries that may otherwise be overlooked or delayed.

The Breakthrough Propulsion Physics Project was created in 1996 and has been implemented in the following sequence of conditional steps, where funding was contingent on successful completion of the prerequisite steps. The documents resulting from each step are shown in parentheses.

1996 – Determined that sufficient scientific foundations exist (NASA TM-107381).

1997 – Determined that affordable research candidates exist (CP-1999-208694).

1998 – Devised means to prioritize and select research tasks (TM-1998-208400).

1999/2000 – Solicited and selected 1st round of research tasks (NRA-99-LeRC-1).

The next stage of the Breakthrough Propulsion Physics project, now reflected in the remainder of this Project Plan, was based on the quantity of quality proposals from the first research solicitation and on overall customer satisfaction. Since more quality proposals were found than anticipated, and since the Breakthrough Propulsion Physics Project received the highest score in an independent review (C. L. Merkle, "Report of the Independent Review Panel of the NASA Space Transportation Research Program, 1999), the level of effort on Breakthrough Propulsion Physics is being increased.

This Breakthrough Propulsion Physics Project Plan provides an authoritative, top-level management description of the project, and is the controlling document for project content and organization. This plan is responsive to the requirements of the NASA Program and Program Management Processes and Requirements (NPG 7120.5A), but has been tailored to meet the unique challenges of breakthrough-focused research. The primary purpose of the plan is to establish the following:

- Project Objectives, Technical Challenges, and Project Approaches
- Research Guidelines, Progress Measures, and Prioritization Criteria
- Project Elements and Implementation Approach
- Project Resources, Schedules, and Controls.

II. OBJECTIVES

The objective of the Breakthrough Propulsion Physics Project is to produce advances in physics that will eventually lead to the development of breakthrough propulsion technologies – technologies that will revolutionize spaceflight and enable interstellar voyages. A significant part of this objective is to ensure that such visionary research is done in a credible and productive manner. A summary chart outlining the Goals, Objectives, Technical Challenges, and Approaches of the BPP Project is provided in the Appendix.

This BPP objective addresses the most visionary objectives and challenges of the ASTP, which itself is responding to the Goals and Objectives of the NASA Aerospace Technology (AT) Enterprise, within the NASA 2001 Strategic Implementation Plan. Through the ASTP, the BPP project address the longer-range and higher-gain ambitions of the following Goals and Objectives:

AT Goal 2: Advance Space Transportation — *Create a safe, affordable highway through the air and into space.*

AT Objective 7: *Reduce the Cost of Taking Payloads to Orbit* **—** Reduce the cost of delivering a payload to Low Earth Orbit (LEO) by a factor of ten by 2010 and reduce the cost of inter-orbital transfer by a factor of ten by 2015. Reduce costs for both by an additional factor of ten by 2025.

AT Objective 8: *Increase Mission Reach* — Reduce the time for planetary missions by a factor of two by 2015 and by a factor of ten by 2025.

AT Goal 3: Pioneer Technology Innovation — *Enable a revolution in aerospace systems.*

AT Objective 9: Engineering Innovation — *Develop the advanced engineering tools, processes and culture to enable rapid, high-confidence and cost efficient design of revolutionary aerospace systems.*

AT Objective 10: Technology Innovation — *Develop the revolutionary technologies and technologies solutions that enable fundamentally new aerospace system capabilities or new aerospace missions.*

To respond to these AT Goals and Objectives, the ASTP is configured as a balanced research and technology program that addresses mid-term and long term needs, Earth to orbit, and in space transportation for Earth orbital, deep space planetary exploration and human exploration. The most visionary extension of these activities includes the development of breakthrough concepts to enable missions that are currently not technically or economically feasible. The BPP Project exists to answer the challenges of this "enabling-breakthrough" facet of the ASTP, specifically within the ASTP Research Investment Area.

To address these enabling-breakthroughs, the *technical objective* of the BPP Project looks beyond Newtonian mechanics; specifically investigating the sciences from which foundations for new technologies emerge. Existing rocket physics and beamed energy physics are fundamentally inadequate for providing timely missions beyond our solar system. Existing propulsion physics cannot enable interstellar missions. Instead of further advancing technologies that are fundamentally limited, the BPP

Project seeks advances in physics to discover ways to circumvent these limitations. To focus this scientific advancement, the BPP Project identified the following three **Technical Challenges** as *the* propulsion breakthroughs that would revolutionize spaceflight and enable interstellar voyages:

> **BPP Technical Challenge 1 - MASS:** Discover new propulsion methods that eliminate or dramatically reduce the need for propellant. This implies discovering fundamentally new ways to create motion, presumably by interactions with the properties of space or by the interactions between matter, energy, and spacetime, including the possibility of manipulating gravity or inertia.
>
> **BPP Technical Challenge 2 - SPEED:** Discover how to circumvent existing limits to dramatically reduce transit times. This implies discovering a means to move a vehicle at or near the actual maximum speed limit for motion through space, or by some other means, such as by interactions with spacetime itself to circumvent normal limits.
>
> **BPP Technical Challenge 3 - ENERGY:** Discover fundamentally new modes of onboard energy generation to power these propulsion devices. This third goal is included since the first two breakthroughs could require breakthroughs in energy generation, and since the physics underlying the propulsion goals is closely linked to energy physics.

These three Technical Challenges primarily address Objective 10 of the NASA Aerospace Technology (AT) Enterprise. Objectives 7 and 8 also apply, but only in regards to the longer-term and higher-gain ambitions. **Table 1** maps the applicability of these BPP Technical Challenges to the AT Objectives 7, 8, and 10.

	AT Objective 7: **Mission Affordability**	**AT Objective 8:** **Mission Reach**	**AT Objective 10:** **Technology Innovation**

BPP Technical Challenge # 1 **MASS**	The mass of contemporary launchers and upper stages is dominated by propellant mass. If alternate means to accelerate spacecraft were discovered that would eliminate propellant, the mass-to-orbit and its associated cost would be substantially reduced. The associated handling costs of propellant would also be eliminated.	**Propellant quantity limits thrust duration and propellant inertia limits acceleration. By eliminating propellant, thrust duration could increase (energy limits then apply), and all the thrust would go to accelerate the vehicle and payload resulting in greater acceleration. The combined effect is higher speeds and shorter transit times.** **Enables missions past the limits of propellant or beamed-energy systems, both with respect to distance and transit time.** **Enables interstellar probe missions within human time-frames.**	**Achievement of this technical challenge would constitute a revolutionary breakthrough for space transportation. Vehicles could be accelerated without the limits of an on-board propellant and without the reliance of energy beamed from Earth. It would enable spacecraft to reach more destinations, faster, and with more autonomy.** **Spin-offs from the discovery of such new physical mechanisms would likely abound.**

BPP Technical Challenge # 2 **SPEED**	Increasing vehicle speed reduces mission duration and the associated operational costs, and provides for quicker return on investments.	Faster vehicles mean shorter missions or greater mission range. A significant breakthrough on this challenge would **enable human interstellar voyages**.	**Fully achieving this technical challenge would constitute a revolutionary breakthrough for space transportation. Human interstellar voyages would be enabled.**
BPP Technical Challenge # 3 **ENERGY**	For outer planetary missions, the energy availability becomes crucial. An energy breakthrough could dramatically improve this situation. In the event that BPP challenge #1 is achieved, energy becomes the next limiting factor. Suitable energy breakthroughs would improve this situation.	In the event that BPP challenge #1 is achieved, energy becomes the next limiting factor. Thrust becomes power-limited and thrust duration becomes energy-limited. Suitable energy breakthroughs would improve this situation to enhance range and/or trip time performance.	Fully achieving this technical challenge would constitute a revolutionary breakthrough for space transportation and for energy production in general. Spin-offs from the discovery of new energy-exchange mechanisms would likely abound

Table 1. Project Challenges in Relation to Aerospace Technology Enterprise Objectives

In addition to the BPP *technical objective* and the associated Technical Challenges, the BPP project has the *implementation objective* of ensuring that such visionary research is done in a credible and productive manner. To accomplish this, the BPP Project is employing the following **Project Approaches**:

- Success is defined as acquiring reliable knowledge, rather than as achieving a breakthrough.
- Research is focused on the immediate make-or-break issues or curious effects identified from comparing the BPP Technical Challenges to established and emerging physics.
- Multiple, divergent research topics are explored simultaneously.
- Progress is sustained as a series of these short-term, incremental tasks.

- Progress is measured using the scientific method.
- Visionary speculations are considered, yet tempered with credible methods and built on credible foundations.

Later sections of this document describe the methods and criteria used to implement and measure adherence to the BPP Technical Challenges and Project Approaches. These methods and criteria themselves address Objective 9 (Engineering Innovation) of the NASA Aerospace Technology (AT) Enterprise, by developing the processes and culture to discover genuinely revolutionary aerospace systems.

III. CUSTOMER DEFINITION AND ADVOCACY

The primary customer for the Breakthrough Propulsion Physics Project is the NASA Advanced Space Transportation Program (ASTP), managed by MSFC. Customer advocacy is ensured by following through with the reporting and review requirements set forth by the customer.

Also, in Fiscal 2000 and extending into 2001, the Breakthrough Propulsion Physics Project received a Congressional earmark directing it to support research at the Institute for Software Research in West Virginia.

In addition to these direct customers, the Breakthrough Propulsion Physics Project also works closely with other NASA centers, government labs, the Department of Defense (DOD), Department of Energy (DOE), universities/academia, and industry. To reach these customers, project descriptions and research results are disseminated in NASA reports, web sites, conferences, and journal publications. The primary web site for these customers is the BPP Project web site at: **http://www.grc.nasa.gov/WWW/bpp/**.

The final and overall customer for the Breakthrough Propulsion Physics Project is the general public. Given the relatively high level of public interest on this project, extra steps have been taken to ensure that this project is accessible to the general public. A public education web site is provided at: **http://www.grc.nasa.gov/WWW/PAO/warp.htm**, and interviews with the press are frequently granted.

IV. PROJECT AUTHORITY

Glenn Research Center has been assigned the Project Management authority for the NASA Breakthrough Propulsion Physics Project by the MSFC-led Advanced Space Transportation Program (ASTP). The BPP Project is under the Research Investment Area within the ASTP, as shown in Figure 1. The BPP Project Manager has full authority to implement and manage the project within the objectives, scope, schedules, and budget established in the Project Plan, as approved by the ASTP Program Manager. The Program Management Councils (PMCs) of the Space Transportation Lead Center (MSFC) and the Performing Center (GRC) are jointly responsible for oversight of the Breakthrough Propulsion Physics Project. The BPP Project Manger also coordinates project changes and reports through the GRC Space Transportation Project Office (STPO).

All efforts within the ASTP that involve investigation of emerging physics for application to space transportation fall within the authority of the Breakthrough Propulsion Physics Project.

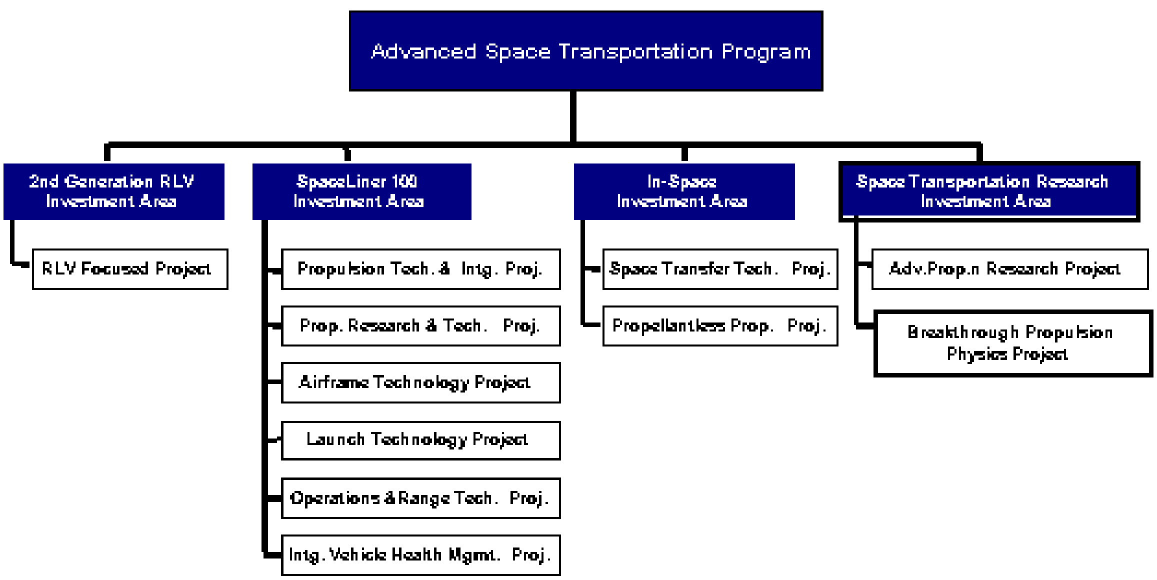


Figure 1. BPP Project Within the ASTP Organization

V. MANAGEMENT

A. Organization and Responsibilities

1. **NASA Headquarters**

The Office of Aerospace Technology (Code R) is the NASA Headquarters office responsible for the Breakthrough Propulsion Physics Project.

2. Field Centers

The field centers involved in the BPP Project presently include the Glenn Research Center (GRC) and the Marshall Space Flight Center (MSFC). The involvement of each center is described below. Note from the Implementation Approach section, that the option to add in-house NASA research at other field centers will be considered as a growth option by the BPP Project.

a. **Glenn Research Center (GRC)**

Glenn Research Center has been assigned the Project Management responsibility for the NASA BPP Project by the MSFC-led ASTP. GRC is responsible for the BPP Project implementation and management. The manager of the Space Transportation Project Office within GRC's Space Directorate assigns the Project Manager for the BPP Project.

Specific duties are assigned as follows, per NPG 7120.5A:

1. **GRC Center Director**

- Performing advanced concept studies in support of Agency and Enterprise Strategic Plans.
- Supporting the Lead Center Director in program formulation.
- Implementing and overseeing the project.
- Developing and maintaining program/ project implementation policies and procedures, compliant with NPD

7120.4A, this document, and ISO 9000.

- Serving as (or designating) chairperson of the Center PMC, consistent with the Lead Center Director responsibilities.

1. **GRC Space Transportation Project Office (STPO) Manager**

To ensure consistency with the ASTP Plan, all applicable NASA procedures and guidelines, and all GRC procedures, guidelines, resources, and workforce utilization, the STPO Manager coordinates BPP Project interactions with the ASTP. The GRC STPO operating procedures are documented in GRC-P6000. This coordination includes the following:

- Project planning, including recommendation of project objectives, requirements, implementation guidelines, project integration, budget and milestones, and preparation of Project Plans.
- Developing, recommending, and advocating the project resources.
- Overseeing the Project Plan.
- Reviewing and reporting project performance.
- Establishing project requirements and performance metrics.
- Allocating and tracking budget to this project.
- Control of project changes.
- Establishing support agreements.
- Complying with applicable Federal law,

regulations, Executive orders, and Agency Directives.

1. **BPP Project Manager**

With the concurrence of the ASTP Manager and the STPO Manager, the BPP Project Manager has full authority to manage the project within the objectives, technical scope, schedules, and budgets established in the ASTP Plan. BPP Project Manager reports functionally to the ASTP Manager. The BPP Project Manager duties include:

- Preparing and maintaining the Project Plan, specifications, schedules, and budgets.
- Allocating and reallocating budgets to Elements
- Establishing support agreements.
- Acquiring and utilizing participating contractors.
- Executing the Project Plan.
- Approving Level III Project Plans.
- Supporting the program management and integration.
- Supporting the program and project planning.
- Reporting project performance and status, including contracts.
- Complying with applicable Federal law, regulations, Executive orders, and Agency Directives.

b. Marshall Space Flight Center (MSFC)

The MSFC, as the Lead Center for Space Transportation Systems Development and the Center of Excellence for Space Propulsion, is Lead Center for the ASTP. The BPP Project is under the Research Investment Area within the ASTP, as shown in Figure 1.

MSFC is also presently responsible for one research task under the authority of the BPP Project (exploration of anomalous gravity effect using superconductors) which is due to be completed July 2001. Participation in future in-house research tasks will be decided by the BPP Project through the process outlined in the Implementation Approach Section.

The definition of specific responsibilities and duties is listed below:

1. **ASTP Program Manager**

- Program planning, including recommendation of program objectives, requirements, implementation guidelines, program integration, budget and milestones, and preparation of Program Plans and Program Commitment Agreements.
- Developing, recommending, and advocating the program resources.
- Executing and overseeing the Program Plan.
- Approving Project Plans and associated changes to these documents.

- Reviewing and reporting program/project performance.
- Establishment of project requirements and performance metrics.
- Allocating budget to this project.
- Control of program changes.
- Establishing support agreements.
- Integrating the planning and executing of individual projects on programs comprised of multiple, interdependent projects.
- Complying with applicable Federal law, regulations, Executive orders, and Agency Directives.

B. Special Boards and Committees

Within the BPP Research Consortium, described in more detail under the Implementation Approach section, a BPP Advisory Council will be established consisting of representatives from NASA and other organizations pertinent to the conduct of BPP research. This will include academia, other Government labs, and industry, as appropriate. This Advisory Council will manage the solicitations, reviews, selections, and reporting of research supported through the Consortium.

C. Management Support Systems

The following management systems will be utilized. In addition, other systems within the agency are being reviewed and considered for use.

1. Automated Resources Tracking

Each Participating Center will utilize its own Centerwide system for tracking funding authority, commitments, obligations, cost and disbursements.

2. Workforce Information Systems

Each participating Center will utilize its own Centerwide workforce system for tracking the civil service workforce associated with the Propulsion Research and Technology Project.

3. [information withheld from public disclosure]

4. [information withheld from public disclosure]

5. [information withheld from public disclosure]

VI. Technical Summary

A. ASTP Requirements

As specified in the ASTP Plan Program Requirements, the BPP Project is required to: "Conduct research into potential in-space propulsion systems beyond the capabilities provided by Newtonian mechanics" and to: "Develop and validate advanced discipline based tools." This requires that the BPP Project seek further advancements in physics related to achieving the BPP Technical Challenges, and to develop the processes necessary to ensure that such visionary research is done in a credible and productive manner. The technical nature of this research is described next, and the methods to carry out this work is described in the Implementation Approach section.

B. Research Topics and Research Guidelines

The BPP Project will pursue multiple, divergent research topics simultaneously to keep a diversified research portfolio. Among the topics of interest are experiments and theories regarding: the coupling of the fundamental forces, force-producing effects, contents and properties of space, the motion of matter and energy through spacetime, interactions with spacetime, energy exchange mechanisms, energy sources, and observed anomalous effects. This includes the study of gravity and electromagnetism, vacuum fluctuation energy, warp drives and wormholes, and superluminal quantum effects.

All research conducted under the BPP Project shall be in the form of incremental, credible, and measurable research that addresses the immediate unknowns, make-or-break issues, or curious effects for a given topic. These unknowns, issues, and effects will be identified by comparing established and emerging physics to the BPP Technical Challenges. By "incremental" it is meant that a given research task shall only be within 1 to 3 years in duration, and aimed at incrementally advancing knowledge as measured by the BPP Readiness Levels (levels described later). Overall progress toward the breakthroughs will be achieved by sustaining a sequence of these incremental tasks over a diverse set of research topics. Typical research tasks suitable for the BPP Project include the following:

Design and/or conduct experiments or empirical observations to:

- Collect more data about a relevant phenomenon or theory, which has already been independently confirmed in the peer-reviewed literature, with a special emphasis on those aspects that are most relevant to the BPP Technical Challenges.
- Perform an independent test to confirm or dismiss a relevant anomalous effect (or device) that has not yet been independently confirmed in the peer-reviewed literature.
- Test a relevant theory that has not yet been independently confirmed in the peer-reviewed literature.
- Apply phenomena and/or theories, which have already been independently confirmed in the peer-reviewed literature, to create a propulsive or energy-exchange effect.

Conduct theoretical and/or analytical work to:

- Identify the remaining critical knowledge gaps and/or make-or-break issues related to the BPP Technical Challenges.
- Compile and analyze data on relevant phenomena and/or theories, which have already been reported in the peer-reviewed literature, with a special emphasis on those aspects that are most relevant to the BPP Technical Challenges.

- Assess and/or compare the propulsion relevance of phenomena and/or theories that have already been independently confirmed in the peer-reviewed literature.
- Assess the validity and propulsion relevance of phenomena and/or theories that have not yet been independently confirmed in the peer-reviewed literature.
- Develop a theory to explain an anomalous effect, which has already been independently confirmed in the peer-reviewed literature, with a special emphasis on those aspects that are most relevant to the BPP Technical Challenges.
- Apply theories, which have already been independently confirmed in the peer-reviewed literature, to describe how to create a propulsive or energy-exchange effect.
- Develop a theory to suggest how to create a propulsive or energy-exchange effect.
- Advance a relevant theory to where it can be empirically tested.

C. Measures of BPP Research Progress

To measure this incremental progress, the Scientific Method has been adapted as a readiness scale in the same manner that the Technology Readiness Levels are used to measure technological progress. More specifically, the readiness scale for the BPP Project consists of three levels for Project Relevance (R), and within each of these three levels are the five levels of the Scientific Method (SM). The Relevance Levels address the degree to which the research is focused on achieving force-producing or energy-exchange effects. A more complete definition of the Scientific Method used for the BPP Project is included in the Appendix. This combination of Relevance and Scientific Method equates to the 15 levels shown below, listed in order of increasing maturity.

<u>Breakthrough Propulsion Physics Readiness Levels</u>

Relevance Level-1: The research topic deals with underlying general physics that pertains to the BPP Technical Challenges, and the topic is at the following level of scientific maturity:

1. R-1 / SM-0 Pre-science (Unconfirmed effect or new information connection)

2. R-1 / SM-1 Problem formulated

3. R-1 / SM-2 Data collected

4. R-1 / SM-3 Hypothesis proposed

5. R-1 / SM-4 Hypothesis tested & results reported

Relevance Level-2: The research topic deals with a critical make-break issue or curious effect relevant to BPP Technical Challenges, and the topic is at the following level of scientific maturity:

6. R-2 / SM-0 Pre-science (Unconfirmed effect or new information connection)

7. R-2 / SM-1 Problem formulated

8. R-2 / SM-2 Data collected

9. R-2 / SM-3 Hypothesis proposed

10. R-2 / SM-4 Hypothesis tested & results reported

Relevance Level-3: The research topic deals with a specific effect or device for producing net force, motion, or energy exchange that address the BPP Technical Challenges, and the topic is at the following level of scientific maturity:

11. R-3 / SM-0 Pre-science (Unconfirmed effect or new information connection)

12. R-3 / SM-1 Problem formulated

13. R-3 / SM-2 Data collected

14. R-3 / SM-3 Hypothesis proposed

15. R-3 / SM-4 Hypothesis tested & results reported*

* Note: After this point, the Technology Readiness Levels become applicable. Level **R-3/SM-4** of the BPP Research Readiness Levels is equivalent to **TRL-1** of the Technology Readiness Levels (Hypothesis tested, basic principles observed & results reported).

D. Research Prioritization Criteria

To evaluate and select research topics for the BPP Project, the criteria described below will be employed. The process to apply these criteria to research submissions is described in the Implementation Approach section. These criteria are a derivative of the selection criteria utilized in the first BPP research solicitation (NRA-99-LeRC-1). Of these, the "Technical Relevance" criteria relate directly to the BPP Technical Challenges that address the AT Goals and Objectives and that address the ASTP Evaluation Criteria. The "Credibility" criteria ensure that the research is credible, and the "Resource" criteria address affordability and timeliness. A more detailed explanation of these criteria is provided in the Appendix.

Technical Relevance:

1: Gain – *Magnitude of performance gain relative to all three of the BPP Technical Challenges, assuming the topic/concept ultimately reaches fruition.*

2: Observability – *Does the topic deal with tangible physical effects or just theory*?

3: Readiness – *The present maturity of the topic/concept under study, as measured against the BPP Readiness Levels*.

4: Progress – *Magnitude of progress to be achieved by the research task, as measured by comparing the BPP Readiness Level that is expected to be achieved upon completion of the task, and the present Readiness Level*.

Credibility:

5: Foundations – *Based on credible references.*

6: Comparisons – *Compared to current credible interpretations*.

7: Test – *Leading toward a discriminating test*.

8: Reliability – *Probability that the task will result in knowledge that will be a reliable foundation for future research decisions*.

Resources:

9: Triage – *Will it be done anyway or must this project support it?*

10: Cost – *Funding required (reciprocal scoring factor)*.

11: Time – *Time required to complete task (reciprocal scoring factor).*

12: Oversight – *Amount of NASA oversight required to ensure successful completion (reciprocal scoring factor*).

Note that *technical feasibility* is not being judged with these criteria. For the kind of fundamental investigations sought by this project, it is too difficult to reliably determine technical feasibility during a proposal review. Such an assessment would constitute a full research task itself. The burden of addressing feasibility, via a discriminating test, is a required part of the research task, and adherence to this requirement is addressed by criteria #7. Instead of judging technical feasibility, proposal reviewers are asked to judge if the task is based on credible foundations and leading to a result that other researchers will consider as a meaningful and reliable conclusion on which to base future investigations. This includes seeking tasks that can reliably demonstrate that certain research approaches are not feasible. This posture of judging credibility rather than pre-judging correctness, is one of the ways that the BPP Project is open to visionary concepts while still sustaining credibility. Note from the Reviews section, that the research *results* are also subject to peer reviews.

E. Facilities.

With the exception of the one task being conducted at MSFC, there are no current in-house NASA facilities being used to support BPP research. After the implementation of the BPP Research Consortium, however, NASA in-house research will be reactivated, and facility usage will be addressed at that time. As discussed in the Implementation Approach section, the in-house NASA research will leverage existing NASA equipment facilities as appropriate.

F. Reporting

Requirements for reporting technical progress are addressed in the Reviews section.

G. Currently Supported Tasks.

Topic: Independent test of Woodward's transient inertia effect.

PI: Dr. J. Cramer, U. of Washington, Seattle, C-78671-K.

BPP Relevance: Directly relevant to a desired effect for Goal 1 (Mass).

Impact: If genuine, this effect may enable thrusting directly against spacetime without propellant.

Progress: From R-3 / SM-3 to R-3 / SM-4 of the BPP Readiness Levels.

Due: March 2001, with public reporting at 2001 JPC, July 2001.

Funds: $49K FY99-00.

Topic: **Investigation of quantum vacuum energy.**

PI: Dr. Jordan Maclay, Quantum Fields, WI, and MEMS Optical, Huntsville, NAS3-00093.

BPP Relevance: Critical make-break issues underlying desired effects for Goals 1 (Mass) and 3 (Energy).

Impact: Addresses existence of, magnitude of, and ability to interact with vacuum energy.

Progress: From R-2 / SM-3 to R-3 / SM-2 of the BPP Readiness Levels.

Due: Dec. 2002, with public reporting at 2001 JPC, July 2001.

Funds: $114K FY99-00, 57K FY01.

Topic: **Experimental test of electrodynamic torsion tensor theory.**

PI: Dr. H. Ringermacher and Washington Univ, St. Louis, MO, NAS3-00094.

BPP Relevance: Critical make-break issues underlying a desired effect for Goal 1 (Mass).

Impact: If genuine, theory provides avenue to explore the possibility of creating asymmetric forces (thrust) from an unverified coupling between mass, charge, and spacetime.

Progress: From R-2 / SM-3 to R-2 / SM-4 of the BPP Readiness Levels.

Due: Jan. 2001, with public reporting at 2001 JPC, July 2001.

Funds: $100K FY99-00.

Topic: Exploration of anomalous gravity effect using superconductors.

PI: Tony Robertson, NASA MSFC.

BPP Relevance: Critical make-break issues underlying a desired effect for Goal 1 (Mass).

Impact: If genuine, effect provides a tangible means to affect gravitational or inertial forces.

Progress: From R-2 / SM-1 to R-2 / SM-2 of the BPP Readiness Levels.

Due: March 2001, with public reporting at 2001 JPC, July 2001.

Funds: $37K FY99-00.

<u>Topic:</u> Investigation of a superluminal hypothesis of quantum tunneling.

PI: Dr. Kevin Malloy, Univ. NM, Albuquerque, NAS-300103.

BPP Relevance: Underlying general physics related to a desired effect for BPP Goal 2 (Speed).

Impact: Addresses make-break issues of light-speed limit (with potential commercial spin-offs).

Progress: From R-1 / SM-3 to R-1 / SM-4 of the BPP Readiness Levels.

Due: Feb. 2002, with public reporting at 2001 JPC, July 2001.

Funds: $90K FY99-00, 80K FY01.

<u>Topic:</u> Investigation of Heaviside Force and Slepian Force Effects.

PI: Dr. Jim Corum, Inst. for Software Research, WV, NAS3-00124.

BPP Relevance: Directly relevant to a desired effect for BPP Goal 1 (Mass).

Impact: If genuine, this effect may enable thrusting directly against spacetime without propellant.

Progress: From R-3 / SM-1 to R-3 / SM-4 of the BPP Readiness Levels.

Due: June 2001, with public reporting at 2001 JPC, July 2001.

Funds: $915K FY00, via CONGRESSIONAL EARMARK (circumvents BPP selection review)

Topic: Investigation of Dirac Deep Energy Levels.

PI: Dr. Robert Deck, Univ, of Toledo, Summer Grant NAG3-2421.

BPP Relevance: Underlying general physics related to a desired effect for Goal 3 (Energy).

Impact: If genuine, this effect may enable new energy source.

Progress: From R-2 / SM-1 to R-2 / SM-2 of the BPP Readiness Levels.

Due: Oct. 2000, with public reporting at 2001 JPC, July 2001.

Funds: $13K FY00.

VII. Schedules

A. ASTP Schedules

Table 2 lists those events and deliverables set by the ASTP to manage and implement the ASTP Program and its Projects. The BPP Project will support these reviews.

Time Frame	Event	Description
January	PLT Quarterly Review	PLT Quarterly Review or Independent Annual Review
Feb.-Apr.	Initial Call for Program Operating Plans (POP)	Call by the ASTP for the project's next fiscal year plans and budget requests
March	Lead Center PMC review	Review of technical and programmatic status.
March	Mid Term Phasing Status Review	Review of budget phasing status (obligations and costing) by ASTP.
May	PLT Project Planning Review	Review by the ASTP of project's next fiscal year plans and budget requests in support of the annual POP.
August	PLT Project Implementation Review	Review by the ASTP of project's next fiscal year implementation plan and project plan
September	Project Plan Due	Project Plan submitted to ASTP for approval signature.
September	Phasing Plan Due	Budget phasing plans (obligations and costing) submitted to ASTP.

Table 2. ASTP Schedule

B. Overall BPP Project Road Map

The overall Breakthrough Propulsion Physics Project Road Map is shown in Figures 2a and 2b. Figure 2a is the 6-year Road Map that includes the schedules for the existing research tasks and the implementation schedule for the BPP Research Consortium.

Figure 2b is the 25-year Road Map showing the overall expected long term evolution of the project.

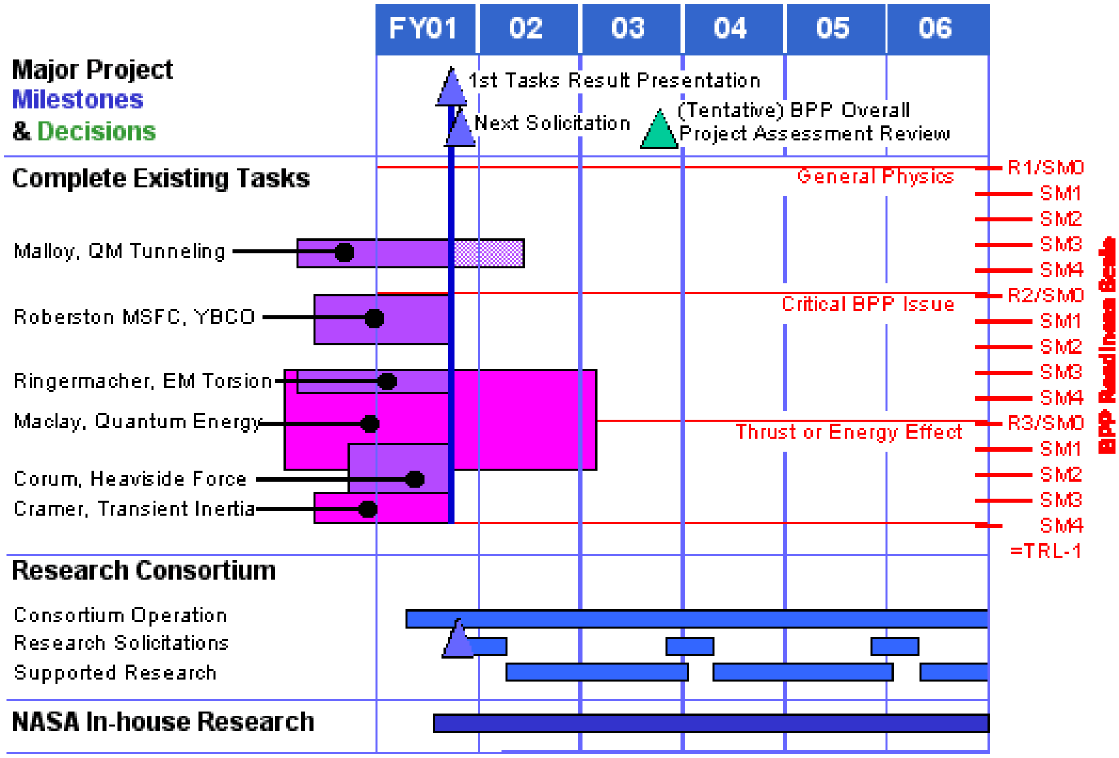


Figure 2a. Breakthrough Propulsion Physics Project 6-Year Road Map

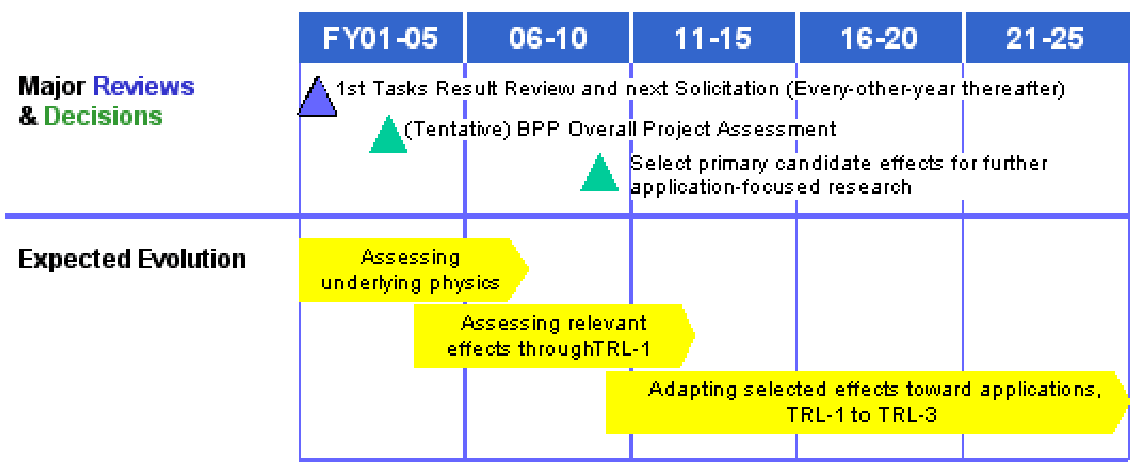


Figure 2b. Breakthrough Propulsion Physics Project 25-Year Road Map

C. Project Milestones

For tracking progress of the Breakthrough Propulsion Physics Project, the following milestones are suggested:

Milestone: Review results of NRA-99-LeRC-1 awarded tasks at the 2001 AIAA Joint Propulsion Conference (GRC Strategic Implementation Plan Milestone).

Output: Six conference papers followed by compilation of these papers into a special issue of the AIAA Journal of Propulsion and Power.

Outcome: Results of research will be used to milestone current progress and assess future research directions.

Completion: Third Quarter, Fiscal Year 2001, specifically July 08 to 11, 2001.

Milestone: Establishment of the BPP Consortium along with the next call for BPP research proposals.

Output: Advisory Council, Reviewer Network, and the Electronic Submission and Review Database now available for NASA utilization.

Outcome: Enhanced and streamlined access to expertise, including university outreach, necessary for timely solicitation and assessment of BPP research.

Completion: Third Quarter, Fiscal Year 2001.

VIII. Resources

IX. Controls

The Breakthrough Propulsion Physics Project is subject to the controls as contained in NASA Procedures and Guidelines, NPG 7120.5A. This BPP Project Plan establishes the top level technical, schedule, and cost controls placed on the project. Reviews of the project to reassess project methods, content, schedules, or budgets are done in concert with the planned ASTP Program reviews, and coordinated through the GRC Space Transportation Project Office (STPO). The GRC STPO operating procedures are documented in GRC-P6000. The responsibilities of the various parties are described below.

A. Responsibilities

Responsibilities are listed in Section V. Management.

B. Interface Controls

ASTP program interfaces are controlled by the ASTP Program Manager. The BPP Project Manager controls any interfaces between BPP subprojects.

C. Change Controls

All revisions to the Project Plan will be coordinated with the Manager of the ASTP. Modifications in the scope or schedule of the tasks covered in this project plan will be tracked by the addition of change pages to this document. Authority to proceed with recommended changes will be at the level appropriate with impact to level of task milestones. The BPP Project Manager will be required to sign all change sheets. The ASTP Manager will be required to sign off on changes that affect Program level milestones. Significant changes are also reported to the Performing Center (GRC) Program Management Council (PMC). The GRC PMC review procedures are documented in LeR-P4.2.

X. Implementation Approach

The following implementation approach for BPP Project is designed to address the visionary BPP Technical Challenges and the Project Approaches identified in the Objectives section, and to address the Research Topics, Guidelines, Measures, and Criteria described in the Technical Summary section. It is also consistent with the other requirements set forth in this Project Plan.

A. Implementation Plan

To Implement the BPP Project, the following strategies and priorities apply:

1. University Outreach Strategy

To access and utilize academic expertise, the BPP Project will be implementing a BPP Research Consortium (discussed in more detail under the Work Breakdown Structure). The Consortium will be implemented through the Ohio Aerospace Institute (OAI), will seek renowned members of the academic community to serve on an Advisory Council, and solicit research proposals from academia and other organizations.

2. Core Competency Strategy

A portion of the BPP Project will involve in-house NASA research (discussed under the Work Breakdown Structure) to ensure the following:

- Sustain a "smart buyer" position in NASA regarding BPP research
- Sustain a core competency and corporate memory for BPP research
- Sustain a propulsion-application emphasis in BPP research
- Leverage existing NASA skills and facilities

3. Research Prioritization

All research supported by the BPP Project, both the in-house research and externally solicited research, will be evaluated by a peer review according to the criteria described in the Technical Summary section, and using a two-stage review process similar to the first BPP research solicitation (NRA-99-LeRC-1). These review functions will be the responsibility of the BPP Research Consortium.

4. Descope Options

Descope options at the project level will be identified by the BPP Project Manger and presented when necessary to the ASTP Program Manager. Any requests for descope options, subsequent to the approval of the project plan, that involve impacts to near-term project milestones or reductions in resource allotments to supporting centers will be coordinated with the supporting centers. Any descope options or proposals that are made as part of the annual update to the project plan will be explained to the ASTP Program Leadership Team prior to the request for signing of the plan.

If it becomes necessary to descope BPP Project activities, the following list of priorities will be followed. The lowest priority will be the first to be descoped or deferred to later Fiscal Years. Also, if feasible, rephasing the allocation of funds for existing tasks will be considered, especially for those tasks spanning more than one year.

BPP Project Implementation Priorities:

1. Complete existing research tasks and associated reporting

2. Establish the BPP Research Consortium, and within the Consortium, the following priorities apply:

    2.1. Establish the Advisory Council

for overall Consortium Operation

2.2. Implement the electronic submission and review database

2.3. Issue the next research solicitation

2.4. Convene the next research workshop

3. Revitalize NASA in-house research, first at GRC, and then at other appropriate centers as resources allow.

B. Project Summary Work Breakdown Structure (WBS)

The elements that will be used to implement the BPP Project are shown in Figure 3, and described below.

Figure 3. BPP Project Summary Work Breakdown Structure (WBS)

1. Existing Research Tasks

The top priority in the BPP Project Implementation Approach is to complete the existing research tasks, ensure that their results are reported, and that these results are made available to the customer (ASTP) and other researchers. The specific research tasks are listed in the Technical Summary section. Reporting requirements are discussed in the Reviews section.

2. BPP Research Consortium

The second priority in the BPP Project Implementation Approach is to establish a BPP Research Consortium. This Research Consortium will facilitate easier collaboration with universities and industry and provide the administrative functions to manage the large number of geographically dispersed participants in BPP research. The consortium will consist of an Advisory Council, will enable Member participation, conduct surveys, solicitations, and prioritization of candidate research, and maintain an electronic database of research proposals and results. OAI will administer the Consortium and serve as a non-voting member of the Advisory Council. The functions of the Consortium are briefly described next.

a. BPP Advisory Council

Within the BPP Research Consortium, a BPP Advisory Council will be established consisting of representatives from NASA and other organizations participating with the BPP Project. To the extent possible, renowned physicists will be sought for key positions on this Advisory Council. Representatives from other participating US Government labs will also be sought. Advisory Council membership is also open to other Consortium Sponsors. The NASA BPP Project Manager will select who shall serve on the Advisory Council. The Chair of the BPP Advisory Council will be the BPP Project Manager or its designee, probably an eminent physicist. The BPP Advisory Council will have the following responsibilities:

- Direct the activities of the BPP Research Consortium.
- Manage solicitations, reviews, and selections of research tasks funded through the BPP Research Consortium.
- Conduct reviews and make recommendations on in-house NASA BPP research.
- Manage the electronic database of the BPP Research Consortium.
- [information withheld from public disclosure]
- Manage workshops or conference sessions in support of the BPP Project.
- Propose additions, replacements, or terminations of Members of the BPP Research Consortium, including Advisory Council membership.
- Alert the BPP Project Manger of any critical issues or opportunities pertinent to the success of the NASA BPP Project objectives, including the identification of project risks and developing risk mitigation strategies.

b. BPP Consortium Membership

In addition to NASA as the prime sponsor for the BPP Consortium, other groups and individuals may become participating members, subject to the recommendation and approval of the Advisory Council, and approval of the NASA BPP Project Manager. There will be different levels of membership, including Sponsors and the Researcher Network. Membership can include participating universities, industries, other government organizations, or individual researchers. Participation may be as a sponsor or as a recipient of research funds. Also, a network of BPP researchers will be part of this membership. This network can be geographically dispersed and will consist of established researchers that can provide reviews of materials sent to the BPP Consortium, as well as identify and/or propose candidate research. Intellectual Property and non-disclosure agreements for the members will be patterned after methods used in existing research consortia managed by the Ohio Aerospace Institute (OAI).

c. BPP Consortium Research Solicitations

The Consortium will issue regular, formal research solicitations. All research submissions will be evaluated by a peer review using a two-stage review process similar to the first BPP research solicitation (NRA-99-LeRC-1). In the first stage, a network of reviewers will numerically score the proposals through the Consortium's electronic submission and review database, which will be patterned after the BPP Research Prioritization Criteria (described in the Technical Summary section and further detailed in the Appendix). In the second stage, the numeric results will be compiled by the Consortium to indicate the top ranking candidates. These results will be submitted to the Advisory Council for their review. The Advisory Council will select which tasks shall get Consortium support and make recommendations on which NASA in-house tasks should be supported outside the Consortium. The Advisory Council is at liberty to not select any tasks in the event that no credible research proposals are received. The BPP Project Manager has final decision-making authority with respect to NASA-funded activities of the Consortium.

d. BPP Electronic Submission and Review Database

To enable the participation of geographically dispersed members, and as a means of providing "clearing house" information about BPP research, the BPP Research Consortium will implement an electronic database. This database will have different levels of access depending on the type of information and Consortium Membership privileges. The publicly-accessible portion of the database will list currently sponsored research, a bibliography of completed research articles, and allow submission of research proposals, suggested topics, or research results. Data will be drawn from this database and submitted to the ASTP STIN as required by the ASTP. The Researcher-Network-accessible portion of the database will provide access to submitted research proposals, suggested topics, or research results so that these can be reviewed and scored. This portion of the database will be tailored to fit the specific Prioritization Criteria of the BPP Project and will have automatic ranking functions based on submission information and review scores. The Sponsor-accessible portion of the database will provide access to the results of the reviews.

e. BPP Workshops and Conferences.

When the BPP Research Consortium and its electronic submission/review database is established, regular BPP conference sessions can be reestablished and managed by the Consortium. The electronic submission and review database will facilitate the peer-review functions needed to screen these conference paper submissions. Workshops will be convened as appropriate. For both workshops and conferences, Proceedings or other forms of reference-able documentation is required.

3. NASA In-house BPP Research

The third priority in the BPP Project Implementation Approach is to reactivate NASA in-house research. The NASA in-house tasks are a separate budget line item within the BPP project, to ensure that NASA has at least one BPP research task in addition to the tasks that are competitively selected through open solicitations. NASA tasks will, however, still be subject to the same conditions of all BPP research – that the research tasks are affordable, near-term, and credible research that will make incremental progress toward the Project's Technical Challenges. The candidate NASA in-house research tasks will be subject to the same peer review selection process as those of the open solicitations. The BPP Research Consortium will conduct these reviews, and the BPP Project Manager will select the NASA in-house tasks after considering the recommendations from the Advisory Council.

Although current budgets only support in-house research at NASA GRC, growth plans for the BPP Project include consideration of supporting in-house work at other NASA centers to take advantage of the unique capabilities offered by each center. All NASA in-house BPP research, regardless of the performing center, will be subject to the same review and selection process.

XI. Acquisition Summary

For the BPP Research Consortium, a Task Agreement within the existing Space Act Agreement with the Ohio Aerospace Institute (OAI), or a new specific Space Act Agreement with OAI, will be used to establish and operate the Consortium. Note that Consortium will be tasked to conduct future calls and awards of BPP research tasks instead of these solicitations being done directly through NASA Procurement (described in Implementation Approach section). For continuation of the BPP Project administrative support, the existing task order contract with the support service contractor will be extended. For the in-house BPP research, services and equipment will be acquired using routine procurement methods. For any required extensions to the existing contracts or grants (listed in Agreements section), amendments to the existing contracts or grants will be used.

XII. PROGRAM/PROJECT DEPENDENCIES

Although there are no other projects upon which the BPP is dependant, there is an existing Phase Two SBIR issued by MSFC to Superconductive Components Inc., Columbus, OH to "Demonstrate the Feasibility of Fabricating a Dual Microstructure YBCO Toroid Suitable for Gravity Shielding Experiments" (97-2-08.02-0261 MSFC). This research, which was initiated prior to the formalization of the BPP Project Plan, is directly applicable to the scope and objectives of the BPP Project.

XIII. Agreements

In the prior years of the BPP Project, many informal collaborations were established on an as-needed basis with other NASA centers, government agencies, universities, and industry. With the establishment of the BPP Research Consortium, these informal collaborations will evolve into formal agreements, where appropriate. The BPP Research Consortium itself will be established using either a Task Agreement within the existing Space Act Agreement with the Ohio Aerospace Institute (OAI), or by establishing a new specific Space Act Agreement with OAI for the conduct of the Consortium.

The BPP Project Manger is responsible for deciding which other agreements shall be formally brought under the auspices of the BPP Research Consortium, which should be directly coordinated with NASA GRC, and which shall remain informal. The BPP Project Manger is also responsible for coordinating with the GRC STPO to ensure that the most appropriate form of agreement is used in each case.

A. Existing Agreements

1) Existing Contracts, Grants, or Other Formal Agreements

Table 3 shows the existing contracts, grants, or other formal agreements currently in place under the BPP Project.

Table 3. Existing BPP Project Formal Agreements

1) Current Collaborations with the NASA GRC BPP Project

a. NASA MSFC, Space Science Directorate: Informal collaboration on

MSFC management of Phase II SBIR: "Demonstrate the Feasibility of Fabricating a Dual Microstructure YBCO Toroid Suitable for Gravity Shielding Experiments" (97-2-08.02-0261 MSFC).

b. NASA MSFC-led SBIR Subtopic # 03.02, "Revolutionary Space Propulsion Technologies," which includes a line for: "Breakthrough propulsion -- Application of newly discovered scientific phenomena to propellantless space transportation, travel near theoretical velocity limits, and energy production far beyond the capabilities of known nuclear sources": Future coordination with the BPP Project of BPP-related tasks through this SBIR process is likely.

c. NASA MSFC, National Space Science and Technology Center (NSSTC): This center is still being formulated (Solicitation Number: 8-1-0-SD-C7058), but it is likely that future coordination with the BPP Project will be necessary.

d. NASA JPL, Advanced Propulsion Technology Group: informal information exchange, including the review of research submissions.

e. NASA Institute for Advanced Concepts (NIAC): informal information exchange and cross-proposal notification.

f. DOD, USAF European Office of Aerospace Research and Development (EOARD): informal assistance on scouting the European theater for BPP relevant activities.

g. DOD, USAF Research Laboratory, Edwards AFB: informal information exchange, including the review of research submissions.

h. DOE, Oak Ridge: informal information exchange, including the review of research submissions.

i. DOE, Los Alamos National Lab: informal information exchange, including the review of research submissions.

j. Numerous professors at various universities: informal information exchange, including the review of research submissions.

k. Numerous researchers at various industries: informal information exchange, including the review of research submissions.

A. Internal NASA Agreements

Task agreements, MOUs or other formal documentation will be established between the Project and implementing organizations as appropriate.

B. External Agreements

GRC will use existing external agreements with the Ohio Aerospace Institute (OAI) to initiate the establishment of the BPP Research Consortium. For research proposal reviews with outside individuals, formal Non Disclosure Agreements are established with each individual reviewer. Additional agreements will be established with small businesses, industrial vendors, universities and other agencies as the project progresses.

C. NASA/DoD Agreements

GRC will continue informal cooperation with DOD's Air Force European Office of Aerospace Research and Development (EOARD), and the Air Force Research Laboratory to assist in identifying relevant research activities and to address National security issues of emerging knowledge. Where appropriate, the BPP Project may utilize an existing "Blanket Reimbursable Interagency Agreement" between the Air Force Research Laboratory and GRC for this cooperation. The points of contact for this Agreement are the NASA GRC Customer Liaison for Organization 9400 (Kathleen K. Needham) and the Chief of the AFRL Requirements Branch, AFRL/XPPR, Wright-Patterson AFB, Dayton, Ohio.

The BPP Project will pursue additional cooperation with the DOE laboratories, where appropriate.

XIV. Performance Assurance

Performance assurance for the Breakthrough Propulsion Physics Project is satisfied through the reviews and reporting requirements dictated by the customer of the BPP Project, specifically the NASA Advanced Space Transportation Program (ASTP), managed by MSFC.

Technical performance assurance is achieved within the BPP Project through the research selection process and criteria described in the Implementation Approach section and the peer review of research results discussed in the Reviews section. Additional methods for performance assurance are also addressed in the Risk Management section.

A quality management plan is not required for the Breakthrough Propulsion Physics Project because there is no flight hardware expected for this project.

XV. Risk Management

For the Breakthrough Propulsion Physics Project, Risk Management takes on a different meaning than that typically associated with flight hardware technology development. In contrast to the issues of equipment reliability commonly associated with such hardware, the BPP Project deals with emerging knowledge. Therefore, the risks are associated with the Project itself and with the relevance, reliability and timeliness of this knowledge.The responsibility for identifying BPP Project risks and developing mitigation strategies will reside jointly with the BPP Project Manager and with the Advisory Council of the BPP Research Consortium. The following list describes those risks that have already been identified and the mitigation strategies that are already being employed in the Breakthrough Propulsion Physics Project (Implementation Approach):

Risk: Credibility damaged by non-rigorous research reporting.

Mitigation: Emphasize building credible, incremental advancements in knowledge, rather than depending on breakthroughs, and by collaborating with academia and other institutions including peer reviews.

Risk: National preeminence damaged by missing relevant breakthrough.

Mitigation: Sustain NASA leadership on BPP research, and forge widespread collaborations to scout for the most advanced research.

Risk: National security weakened from premature disclosures.

Mitigation: DOD participation included to ensure national security issues are addressed. Threshold of attention is when devices can be engineered. (Note: With regards to National security and consideration of ITAR restrictions, the threshold for security assessment is when a BPP research concept achieves Technology Readiness Level –1 [Basic principles observed and reported] and when the concept can readily engineered into a marketable device. Prior to this level of technical maturity, all BPP research is considered Basic Research and not subject to ITAR restrictions.)

Risk: National strength weakened from missing market opportunities.

Mitigation: Ensure that BPP progress and suitable opportunities are reported to US Industry, and include opportunity for industry involvement in the conduct of the BPP project (Consortium).

Risk: Project success put at risk by reductions in resources.

Mitigation: Descope options and Project priorities are discussed in the Implementation Approach section.

XVI. Environmental Impact

Appropriate environmental impact assessment shall be developed as needed.

XVII. SAFETY

Existing NASA safety procedures will be followed.

XVIII. Technology Assessment

This section has been tailored out since the BPP Project is for fundamental scientific research instead of technology development.

XIX. Commercialization

The BPP Project addresses commercialization possibilities in two ways. The first manner is by utilizing the Commercial Technology Utilization Office at GRC to ensure that the technologies developed within the BPP project have adequate opportunity for inclusion and /or immersion into commercial arenas and opportunities for direct commercial applications. The second is by including the opportunity for industry membership in the BPP Research Consortium.

XX. Reviews

A. Management Reviews

Management Reviews will be scheduled during the life of the project. The type and frequency of the reviews will be established according to the unique needs of the Project and the Program Offices. The reviews will be scheduled to keep program and project management informed of the current status of existing or potential problem areas. Special reviews by any level of management will be conducted when the need arises. See Table 4 for a summary of program level reviews.

Time Frame	Review	Description
January	ASTP IAR	Independent program-level review of ASTP.
March	Lead Center PMC review	Review of technical and programmatic status.
May	PLT Project Planning Review	Review by the ASTP of project's next fiscal year plans and budget requests in support of the annual POP.
August	PLT Project Implementation Review	Review by the ASTP of project's next fiscal year implementation plan and project plan

Table 4. ASTP Program Level Review Schedule

Efficient management of the Breakthrough Propulsion Physics Project requires effective communication through reviews and reports. The following reviews have been established to communicate project progress and information to working groups, management and industry.

1. ASTP Program Leadership Team (PLT) Reviews

The PLT will formally review the ASTP Projects two times each year. This review is an effective means to provide project information to the top management of ASTP in terms of status, performance, issues, budget and plans. Additionally, this review serves as a two-way platform to exchange project-related ideas, issues and concerns and to revalidate the project.

2. Lead Center Program Management Council (PMC) Review

The Marshall Space Flight Center Lead Center PMC will review ASTP Projects annually. The reviews will cover overall status information, including schedule, change, performance, funding, interfaces coordination, and other management and technical topics. The Lead Center PMC review will also assess project progress against metrics and criteria proposed in procurement instruments.

3. An Independent Annual Review (IAR)

An IAR will be performed to assess the progress and continued executability of the ASTP. The subcommittees of the Aero-Space Technology Advisory Committee (ASTAC) will augment their traditional peer review process by performing an annual program review of ASTP to assess performance against plan, including technical performance, schedule and cost. Additionally the subcommittees will assess the future executability of the program plan. The subcommittee compiles its report and provides findings to the Lead Center PMC.

4. Other Reviews

Other independent reviews will be scheduled as required and will include the participation of all NASA Centers involved in the BPP Project.

B. Technical Reviews

Technical Reviews will be scheduled during the life of the project to report technical progress. Reviews for the selection of research proposals are addressed in the Implementation Approach section and do not apply to this section. The type and frequency of technical reviews will be established according to the unique needs of the Project and the Program Offices. The reviews will be scheduled to give program management and the aerospace community an overview of the emerging knowledge base on Breakthrough Propulsion Physics. Currently planned technical reviews include:

1. Review of 1st Round of Research Tasks

A review of all tasks currently supported by the BPP project will occur in a session at the July 2001 37th AIAA/ASME/SAE/ASEE Joint Propulsion Conference (JPC) in Salt Lake City, Utah, July 08 to 11, 2001. Other papers about BPP related research results will also be solicited for this conference session. Furthermore, papers received at this BPP session will be considered for inclusion into a special issue of the "AIAA Journal of Propulsion and Power" devoted to the status and directions of BPP – intended to be a "mile marker" publication for this topic. The review team for this special publication will consist of the BPP Consortium Advisory Council or its designees.

2. Review of Research Results

All tasks supported by the BPP Project are required to deliver reports to the BPP Project Manager for tracking progress, and a peer-reviewed Final Report for dissemination of results. The requirements for these reports are as follows:

a. Internal Research Progress Reports

All BPP-supported research tasks will be required to deliver, to the BPP Project Manager, a Final Report, Quarterly Technical Progress Reports, and for those tasks that exceed one-year duration, Annual Progress Reports. Any data acquired during the completion of the task shall also be delivered.

b. Peer-Review of Externally Published Research Results

All tasks currently supported by the BPP Project are required to deliver a Final Report in a form "suitable for submission to a peer-reviewed journal." Although it cannot be made a requirement to secure a publication in a scientific peer-reviewed journal, the intent is to have the results of BPP-supported research submitted through scientific journals in order to obtain a peer review of the results. In the event that a Final Report from a BPP-sponsored task is rejected from a peer-reviewed journal, even after one full iteration of responding to reviewers' comments, the report shall be published as a NASA Contractor Report, and shall include the rejecting reviewers' comments as an addendum. The BPP Consortium Advisory Council will also be invited to add comments to this addendum.

2. Biannual BPP Technical Conference Sessions

Contrary to prior years, The BPP Project will be postponing the support of annual BPP technical sessions. (Previously the BPP project held sessions at the annual Space Technology Applications International Forum [STAIF], January-February, Albuquerque NM.) When the BPP Research Consortium and its electronic submission and review database is established, conference sessions can be reestablished and managed by the Consortium. These conference sessions will be held every other year. The electronic submission and review database will facilitate the peer-review functions needed to screen these conference paper submissions.

XXI. tailoring

The requirements of NASA Policy Directive (NPD) 7120.4A and NASA Procedures and Guidelines (NPG) 7120.5A apply to this program as tailored by the ASTP Program Plan and this Project Plan. Specifically, this Project Plan has tailored the following:

- **Quality management plan is not required for the Breakthrough Propulsion Physics Project because there is no flight hardware expected for this project. Project quality addressed via Performance Assurance and Technical quality addressed via the research selection process described in the Technical Summary and Implementation Approach. Research quality addressed under Technical Reviews.**
- **Technical Summary tailored to fit the unique research requirements of the BPP Project instead of the established template, which is more suitable for technology development.**
- **Risk Management addresses project risks rather than hardware risks since the BPP Project is basic research and not hardware development. Also, the descope options are cited in Risk Management.**
- **Technology Assessment not required since the BPP Project is basic research and not technology development.**

XXII. RECORDS RETENTION

The Breakthrough Propulsion Physics Project Manager will determine which project records will be retained and for how long, in order to ensure that a permanent record of the project and lessons learned are available to benefit future NASA projects. Where possible, publicly available publications will be used to document the results of the project.

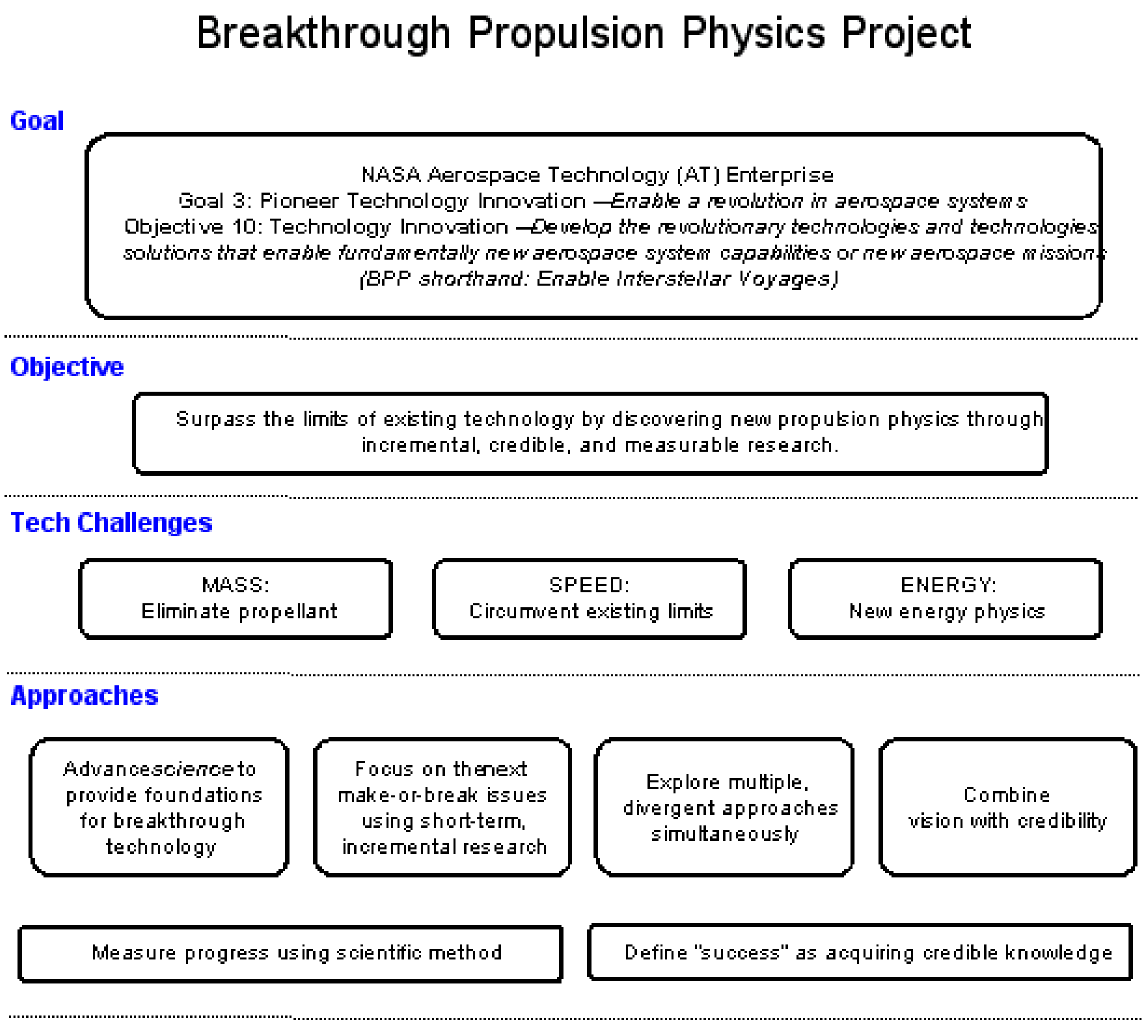
XXIII. CHANGE LOG

EFF. DATE	STATUS	DOC. REVISION	DESCRIPTION
Dec. 4, 2000	Baseline	–	Initial Issue

APPENDIX

A. BPP Overview Chart

This "GOTCHA" chart of the Goals, Objectives, Technical Challenges, and Approaches behind the BPP Project, provides a quick overview of the nature of the BPP Project.



B. BPP Definitions of Scientific Methods Levels

The following list provides the definitions for the Scientific Method Levels as used for measuring research progress for the BPP Project. Note that the scientific method levels below have two descriptors; "Empirical" for approaches based on the emergence of a ***new*** empirical effect, and "Theory" for approaches based on theory.

SM-0: PRE SCIENCE

(Empirical) Observations of an unconfirmed anomalous effect have been reported (includes claims of unverified devices), or

(Theory) A *correlation* between a desired goal (or unsolved problem) and the existing knowledge base has been articulated.

SM-1: PROBLEM FORMULATED

(Empirical) In the case of prior observations of an unconfirmed anomalous effect, an experiment has been defined that can collect the data required to isolate and characterize the effect, or

(Theory) A goal (or problem) has been defined specifically enough to identify the specific remaining knowledge gaps toward achieving the goal (or solving the problem).

SM-2: DATA COLLECTED

(Empirical) An anomalous effect has been ***independently*** verified or attributed to misinterpretations of conventional effects, or

(Theory) The relevant data to fill the critical knowledge gaps, identified in the previous step, have been collected through experiment, observation, or mathematical proof (this level includes assessments of theory using mathematical analysis).

SM-3: HYPOTHESIS PROPOSED

(Empirical) A mathematical representation of the physical principles underlying an anomalous effect has been offered to explain the effect and predict additional (testable) effects, or

(Theory) A mathematical representation of the relation between physical phenomena has been offered that addresses the goal (or problem) formulated previously.

SM-4: HYPOTHESIS TESTED & RESULTS REPORTED

The hypothesis has been tested by comparison to observable phenomena or by experiment sufficiently to determine if it appears viable, and the results reported. (NOTE: In the context of this BPP project, testing of a hypothesis must be *empirical*; that means it must be done by comparison to observable phenomena or by experiment, rather than just by mathematical proof. Although mathematical proof can be used to test the consistency of a theory against the *known* laws of physics, such a mathematical test alone is not sufficient to warrant "SM-4." Instead, a mathematical test of a theory warrants a "SM-2.")

C. BPP RESEARCH PRIORITIZATION CRITERIA

The following is a more thorough description of the Prioritization Criteria used to review BPP Research Proposals. This descriptions provides a narrative to accompany all the Criteria introduced in the Technical Summary section of the BPP Project Plan, including the scoring gradations used to score compliance with each criteria. The composite score is achieved by multiplying the individual scores. This has the feature whereby a failure to meet any mandatory criteria (zero score possible on criteria) will result in a total score of zero.

Technical Relevance Criteria (1-4)

1: Gain – *Magnitude of performance gain relative to all three of the BPP Technical Challenges, assuming the topic/concept ultimately reaches fruition*.

The proposed work must seek advances in physics that are relevant to propulsion or power. This program looks beyond the known methods, searching for further advances in science from which genuinely new technology can eventually emerge - technology to surpass the limits of existing methods. As such, it is mandatory that the proposed work seek advances in science that are in some way relevant to the program’s three propulsion challenges or any critical issues related to these goals. For each of the three program goals, specify which of the statements best describes the ultimate achievable performance of the concept being addressed by the proposal. Granted, it may be difficult to predict this ultimate impact since the concepts may be far from fruition. Note that this is a mandatory criteria which means that a failure to meet this criteria (a zero score on all three sub-criteria) will result in a total score of zero. Since the scores for 1.1, 1.2, and 1.3 will be added, it is only mandatory that one of the three goals be addressed.

Scoring Gain = 1.1 + 1.2 + 1.3

1.1. BPP Technical Challenge 1 - MASS: *Discover new propulsion physics that eliminates or dramatically reduces the need for propellant*

Scoring Gradations:

0 Not applicable to this goal (default answer if no answer specified).

2 Applicable, but potential impact unknown.

3 Intended to significantly reduce propellant requirement.

4 Intended to eliminate the need for propellant and need for directed energy.

(The term; "directed energy," means any form of energy sent from a central location such as from the Earth or Sun)

1.2. BPP Technical Challenge 2 - SPEED: *Discover how to circumvent existing speed limits to dramatically reduce transit times*

Scoring Gradations:

0 Not applicable to this goal (default answer if no answer specified).

2 Applicable, but potential impact unknown.

3 Intended to eliminate speed constraints caused by propellant or energy limits.

4 Intended to circumvent the light speed limit.

1.3. BPP Technical Challenge 3 - ENERGY: *Discover new energy physics to power these propulsion devices at levels sufficient for interstellar flight*

Scoring Gradations:

0 Not applicable to this goal (default answer if no answer specified).

2 Applicable, but potential impact unknown.

3 Better energy conversion physics, but still limited to a consumable onboard supply.

4 Intended to provide energy sources and conversion methods accessible in flight.

2: Observability – *Does the topic deal with tangible physical effects or just theory*?

Since this NASA project is interested in advancements that can eventually lead to new technology and since empiricism is necessary to validate theories, there is a decided preference toward observable experiments over analytical studies. Experiments, being hardware, are considered closer than theory to becoming technology. Also, experiments are considered a more direct indicator of how nature works. Theories are *interpretations* to explain observations of nature, while the empirical data *is* nature. Another concern is that some theories are not likely to lead to physical effects that could be engineered into a space vehicle (e.g., black hole theories). The most desired work is experiments that are coupled with theory. Experiments that are backed by a sound theoretical foundation provide a means to numerically assess the potential utility and scalability of the effects beyond just a single demonstration experiment. The next preference is for experimental work by itself, for example to independently verify a claimed anomalous effect. The next preference after that is theoretical work by itself. Lowest on this priority scale is work that only involves comparative studies of existing approaches or literature searches.

Scoring Gradations:

1 Comparative study, data collection, or literature search.

2 Theoretical work only, without empirical investigations.

3 Experimental tests or empirical observations only.

4 Experiment or empirical observations coupled with theory.

3: Readiness – *The present maturity of the topic/concept under study, as measured against the BPP Readiness Levels.*

Scoring: This Criteria and Criteria #4 are answered jointly in the Scoring Gradations shown under Criteria #4.

4: Progress – *Magnitude of progress to be achieved by the research task, as measured by comparing the BPP Readiness Level that is expected to be achieved upon completion of the task, and the present Readiness Level.*

Scoring Progress: BPP Level After - BPP Level Now **-** This Criteria and Criteria #3 are answered jointly in the Scoring Gradations shown below.

Using the BPP Readiness Levels, specify the status to be achieved upon **completion** of the proposed task **("after")**, and of status **today ("now")** for the concept being addressed. Answer this question within the limits of the specific, incremental issue or effect being addressed by the proposal. Note that "successful completion" is defined as completing the proposed work and learning more about reaching the breakthrough, rather than actually achieving the breakthrough. Negative test results are still progress.

Scoring Gradations:

Now	**After**	**BPP Readiness Levels**
		Readiness level -1: General physics pertinent to the BPP Technical Challenges
1	1	**R-1 / SM-0 Pre-science (Unconfirmed effect or new information connection)**
2	2	**R-1 / SM-1 Problem formulated**
3	3	**R-1 / SM-2 Data collected**
4	4	**R-1 / SM-3 Hypothesis proposed**

5	5	**R-1 / SM-4 Hypothesis tested & results reported**
		Readiness level -2: Deals with a critical make-break issue or curious effects directly related to the BPP Technical Challenges
6	6	**R-2 / SM-0 Pre-science (Unconfirmed effect or new information connection)**
7	7	**R-2 / SM-1 Problem formulated**
8	8	**R-2 / SM-2 Data collected**
9	9	**R-2 / SM-3 Hypothesis proposed**
10	10	**R-2 / SM-4 Hypothesis tested & results reported**
		Readiness level -3: Deals with a specific effect or device for producing net force, motion, or energy exchange that address the BPP Technical Challenges
11	11	**R-3 / SM-0 Pre-science (Unconfirmed effect or new information connection)**
12	12	**R-3 / SM-1 Problem formulated**
13	13	**R-3 / SM-2 Data collected**
14	14	**R-3 / SM-3 Hypothesis proposed**
15	15	**R-3 / SM-4 Hypothesis tested & results reported = TRL 1 Basic principles observed and reported**
16	16	**TRL-2 Application conceptual design formulated**
17	17	**TRL-3 Conceptual design tested analytically or experimentally**

Credibility Criteria (5-8)

5: Foundations – *Based on credible references.*

The proposed work must be based in some way on data or theories that are in the peer-reviewed literature. Note: requiring reference citations is one of the techniques to filter out "fringe" submissions. This is a *mandatory* criteria which means that a

failure to meet this criteria (zero score) will result in a total score of zero. Grade this criteria on how well the proposer identified the most relevant references for their topic of investigation.
If new theory: In the case of new theories that are not yet in the literature, the offeror must cite peer-reviewed references of the data or phenomenon with which they are claiming consistency. It is not necessary that the offeror agree with current interpretations of this data, but it is mandatory that the theories are consistent with credible empirical evidence.
If in literature: In those cases where the offeror asserts that they are building upon work that has already achieved Level I (Problem Formulated) or higher on the Scientific Readiness Levels, they must cite references to support this. For example, if they are claiming that they are testing a hypothesis that is already in the peer reviewed literature, they must cite that reference.
If new effect: In cases where *unconfirmed* anomalous effects are being discussed, the offeror must site relevant peer-reviewed references. If prior tests of the effect have been performed and reported in the literature, these references must be cited. If the effect has not yet been reported in the literature, then the offeror must at least cite peer-reviewed references that describe related phenomena to demonstrate why the newly observed phenomena is anomalous.

Scoring Gradations:

0 F- Fails to meet.

1 D- Poor or well below average.

2 C- Average.

3 B- Good or well above average.

4 A- Excellent or outstanding, meeting the criteria to the maximum amount.

6: Comparisons – *Compared to current credible interpretations*.

To ensure that an idea is oriented toward the goals of the project, and to ensure that the authors have done their homework, it is required that the proposal articulate how the proposed work compares to existing approaches, relative to the BPP Technical Challenges. This not only checks for relevance, but also positions the work to address the criteria of a discriminating test. Note: requiring reference citations is one of the techniques to filter out "fringe" submissions. This is a mandatory criteria which means that a failure to meet this criteria (zero score) will result in a total score of zero.

If new theory: In the case of new theories, it is mandatory that the new theories be compared to the contemporary theories that address the same phenomena. Reference citations for the contemporary theories are required. The comparison must explain why the new theory would be more advantageous to the propulsion challenges than the contemporary theories.

If confirmed effect: In cases where an anomalous effect is being investigated that has already been confirmed in the peer-reviewed literature, the proposal must explain why the effect might be advantageous to the propulsion challenges and why the proposed investigation is more applicable to addressing the propulsion challenges than prior or ongoing investigations into the effect. Reference citations for the prior or ongoing investigations are required.

If unconfirmed effect: In cases where unconfirmed anomalous effects are being investigated, the proposal must explain why the proposed investigation is more applicable than existing or past investigations into the effect. This discussion must acknowledge other possible conventional explanations for the anomaly. In the case where prior null test results have been published, the offeror must cite these and explain why the prior tests were incomplete or why a reinvestigation is warranted. Reference citations for the prior or ongoing investigations of the effect are required. Also the proposal must explain why the effect (if genuine) might be advantageous to the propulsion challenges. Grade this on how well the proposer identified the most relevant literature and on their understanding of this literature.

Scoring Gradations:

0 F- Fails to meet.

1 D- Poor or well below average.

2 C- Average.

3 B- Good or well above average.

4 A- Excellent or outstanding, meeting the criteria to the maximum amount.

7: Test – *Leading toward a discriminating test.*

It is required that the proposed work be leading toward a discriminating test or actually be a discriminating test. If a discriminating test can be completed within the budget and time guidelines requested of proposals, it is necessary that the test actually be proposed. Otherwise, it is sufficient to propose to advance a theory toward testable predictions or to design an experiment to perform a make-or-break test for sometime in the future. The offeror must identify the critical make-or-break issues for their immediate area of investigation. Also, the proposed next-step must be consistent with the scientific method, with due consideration for the current status of the topic as specified by the offeror. Also note that, depending on the status of the proposed task, independent verification may be warranted. In such a case, the vested interests of the Principle Investigator must be taken into account. This is a mandatory criteria which means that a failure to meet this criteria (zero score) will result in a total score of zero.

If new theory: In the case of new theories, it is mandatory that the new theories are at least matured to the point where mathematical models are offered (this is one of the "fringe" filters). Then, either mathematical analysis; further development to predict testable effects; comparison to credible empirical observations; or experimental tests must be proposed that can bring the theory closer to a correctness resolution. An actual empirical test is preferred.

If confirmed effect: In cases where an anomalous effect is being investigated that has already been confirmed in the peer-reviewed literature, the next logical step would be to develop a theory to describe the anomaly. The criteria stated above for new theories would then apply to this situation as well.

If unconfirmed theory: In cases where new, unconfirmed, anomalous effects are being investigated, a discriminating test must be suggested that could distinguish between possible conventional explanations or whether this is a genuine new effect. (This is one of the "fringe" filters). The work will be considered more credible if the proposal concentrates only on the experimental methods rather than on speculating on a new cause for the effect.

Scoring Gradations:

0 F- Fails to meet.

1 D- Poor or well below average.

2 C- Average.

3 B- Good or well above average.

4 A- Excellent or outstanding, meeting the criteria to the maximum amount.

8: Reliability – *Probability that the task will result in knowledge that will be a reliable foundation for future research decisions*.

Successful completion of the research task is defined as learning more about reaching the breakthrough, rather than actually achieving the breakthrough. Negative test results are progress. What is required for successful completion is that the work reaches a credible resolution that is clearly communicated. If it is likely that the work can be completed within the funding and time allocations specified, and that the results will be accepted by other researchers as a credible foundation for future work, a high score is warranted. Base this assessment on a combination of the realism of the proposed work, its cost and schedule, and on the credentials of the proposed research team and their facilities. If cost sharing is mentioned in the proposal, judge this criteria on the total resources to be devoted, not just the amount to be charged to NASA. Consider that the clarity and quality of the proposal is a good reflection of the clarity and quality of the final product. Note too that, depending on the status of the proposed task, independent verification may be warranted. In such cases the vested interests of the Principle Investigator must be taken into account to ensure that there is no conflict of interest in the outcome of the device, phenomenon, or theory under test. This is a mandatory criteria which means that a failure to meet this criteria (zero score) will result in a total score of zero.

Scoring Gradations:

0 F- Fails to meet.

1 D- Poor or well below average.

2 C- Average.

3 B- Good or well above average.

4 A- Excellent or outstanding, meeting the criteria to the maximum amount.

<u>Resource Criteria (9-12)</u>

9: Triage – *Will it be done anyway or must this project support it?*

Specify which statement best describes the situation. Note that this is not a mandatory criteria. A minimum score here will only result in demoting an overall "A" grade to a "C" grade.

Scoring Gradations:

1 Certain to be credibly done without the support of the BPP Project.

2 Unknown.

4 Exclusively suited to the BPP Project.

10: Cost – *Funding required (reciprocal scoring factor)*.

Scoring: Enter proposed cost.

11: Time – *Time required to complete task (reciprocal scoring factor)*

Scoring: Enter proposed duration.

12: Oversight – *Amount of NASA oversight required to ensure successful completion (reciprocal scoring factor*).

This criteria is based on experiences where added costs were incurred from the amount of NASA oversight required to ensure a credible product. This criteria is scored by adding an additional labor factor (Full Time Equivalent, FTE) and its associated Program Support costs to the proposal costs that will take into account the overhead for assisting in the completion of the task.

Scoring Gradations:

-- F -- Fails to meet. No amount of oversight will result in a credible product.

+1.5 FTE NASA will have to be an active participant in the research and reporting to ensure that the research and the reporting meet the credibility requirements.

+0.5 FTE Unknown.

+0.2 FTE Assistance will be required to review and possibly rewrite reports to ensure that the research and the reporting meet the credibility requirements.

+0.0 FTE No assistance required. PI has demonstrated ability to routinely conduct rigorous research and credibly report the results.

Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004

Millis, M. G., NASA Propulsion Physics Program, **NASA TM-1998-208400**, 1998. In *Missions to the Outer Solar System and Beyond, Second IAA Symposium on Realistic Near-Term Advanced Scientific Space Mission*, Aosta Italy, June 29 - July 1, 1998, International Academy of Astronautics, Genta, G., ed., pp. 103-110.

web version 08/20/99

Note: Figures did not transcribe correctly from original report.

NASA BREAKTHROUGH PROPULSION PHYSICS PROGRAM

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Abstract - In 1996, NASA established the Breakthrough Propulsion Physics program to seek the ultimate breakthroughs in space transportation: propulsion that requires no propellant mass, propulsion that attains the maximum transit speeds physically possible, and breakthrough methods of energy production to power such devices. Topics of interest include experiments and theories regarding the coupling of gravity and electromagnetism, vacuum fluctuation energy, warp drives and wormholes, and superluminal quantum effects. Because these propulsion goals are presumably far from fruition, a special emphasis is to identify affordable, near-term, and credible research that could make measurable progress toward these propulsion goals. The methods of the program and the results of the 1997 workshop are presented. This Breakthrough Propulsion Physics program, managed by Glenn Research Center, is one part of a comprehensive, long range Advanced Space Transportation Plan managed by Marshall Space Flight Center.

1 INTRODUCTION

New theories and phenomena have emerged in recent scientific literature that have reawakened consideration that propulsion breakthroughs may be achievable - the kind of breakthroughs that could make human voyages to other star systems possible. This includes literature about warp drives, wormholes, quantum tunneling, vacuum fluctuation energy, and the coupling of gravity and electromagnetism. This emerging science, combined with the realization that rockets are fundamentally inadequate for interstellar exploration, led NASA to establish the "Breakthrough Propulsion Physics" program in 1996.

This paper introduces this program and several of the candidate research approaches that have already been identified. In particular, this paper explains the methods used by this program to conduct such visionary work as a lesson for other institutions who may also wish to begin similar programs. Also, to give an indication of some of the possible next research steps, the results of the 1997 workshop are presented.

2 BACKGROUND

Prior to 1996 the implications of emerging science to the challenges of space propulsion were only sporadically studied, and then mostly by individual researchers who did so on their own time. Occasionally research and workshops were formally supported [1-11], but progress was generally slow.

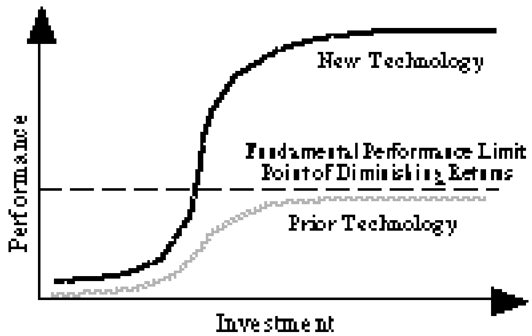
In 1996, the NASA Marshall Space Flight Center (MSFC) was tasked to formulate a comprehensive strategy for advancing propulsion for the next 25 years and they were requested to make this strategy more visionary than previous plans. This strategy, called the "Advanced Space Transportation Program (ASTP)," spans the nearer-term technology improvements all the way through seeking the breakthroughs that could revolutionize space travel and enable interstellar voyages [12].

To address the most visionary end of this scale, MSFC sought out the work of the NASA Glenn Research Center. Individuals at Glenn had already been working on these topics [9, 10, 13-15] and Glenn had experience working with far-future ideas through their "Vision-21" exercises [5, 7, 16]. By applying the lessons learned from Vision-21 and by forging collaborations amongst the individuals across the country who were already working on these topics, Glenn established the "Breakthrough Propulsion Physics" program to advance science to address the goals of breakthrough space flight.

3 PROGRAM FOUNDATIONS

As the name implies, this program is specifically looking for *propulsion breakthroughs* from *physics*. It is not looking for further *technological* refinements of existing methods. Such refinements are being explored in other programs under the ASTP. Instead, this program looks beyond the known methods, searching for further advances in science from which *genuinelynew* technology can emerge - technology to surpass the limits of existing methods.

There is a historical pattern to technological revolutions, where new methods surpass the fundamental limits of their predecessors [17]. Steam ships surpassed sailing ships, aircraft surpassed ground transportation, rockets surpassed aircraft, and now the search has begun for new methods to surpass rockets. This evolutionary pattern is summarized in Figure 1. To sustain technological preeminence, new methods must be sought when the existing method is reaching the limits of its underlying physical principles (the upper right asymptote of the S-curve in Figure 1), and when new clues are emerging for alternative methods that might surpass these limits [17].



In the case of spaceflight, rocket technology is reaching the performance limits of its underlying physical principles and new clues are emerging from science that might lead to new propulsion principles.

There have been several recent advances in science that have reawakened consideration that new propulsion mechanisms may lie in wait of discovery. Recent experiments and Quantum theory have revealed that space may contain enormous levels of vacuum electromagnetic energy [18, 19]. This has led to questioning if this vacuum energy can be used as an energy source [20, 21, 11] or a propulsive reaction mass for space travel [22]. Next, new theories suggest that gravity and inertia are electromagnetic effects related to this vacuum energy [23, 24]. It is known from observed phenomena and from the established physics of General Relativity that gravity, electromagnetism, and spacetime are inter-related phenomena [25]. These ideas have led to questioning if gravitational or inertial forces can be created or modified using electromagnetism [22]. Also, theories have emerged from General Relativity about the nature of spacetime that suggest that the light-speed barrier, described by Special Relativity, might be circumvented by altering spacetime itself. These "wormhole" [26, 27] and "warp drive" theories [28, 29] have reawakened consideration that the light-speed limit of space travel may be circumvented. Today, it is still unknown whether these emerging theories are correct and, even if they are correct, if they can become viable candidates for creating propulsion breakthroughs.

Although these emerging possibilities are of keen interest to space technologists, the general scientific community is more concerned with answering questions of the origin of the universe, missing matter, black holes, and high-energy particle interactions. To advance physics to solve the challenges of space travel a focused effort is required. It should also be pointed out that such an application-oriented program also provides new opportunities for science itself. In the first step of the scientific method, where one clearly formulates the problem to guide the search for knowledge, this NASA program has a unique problem: space flight. This program is specifically interested in the physics of how to propel a space vehicle as far and as fast as possible with the least amount of effort. Such a focus will present different lines of inquiry than the more general physics inquiries. By asking different questions and looking along a different path, this program provides an opportunity for physicists to search for discoveries that may otherwise be overlooked or delayed.

Since such work is more visionary than usual aerospace endeavors, this program faces special programmatic challenges in addition to the technical challenges of discovering the desired breakthroughs. Fortunately, much has been written about the historical lessons from technological revolutions [17], scientific revolutions [30], and the human creative process [31]. Many of these lessons were incorporated into the NASA Glenn "Vision-21" activities [16], and have been incorporated into the Breakthrough Propulsion Physics program. In the descriptions of the program's goals, objective, methods, and research priorities that follow, these lessons are presented.

3.1 Program Goals

The first step toward solving a problem is to define the problem. To determine the specific technical goals of the program, the "Horizon Mission Methodology" [32] was used. This method forces paradigm shifts beyond extrapolations of existing technologies by using *impossible* hypothetical mission goals to solicit new solutions. By setting impossible goals, the common practice of limiting visions to extrapolations of existing solutions is prevented. The "impossible" goal used in this exercise was practical interstellar travel. From conducting this exercise, the three major barriers to practical interstellar travel were identified and then set as the program's technical goals. These are ***the*** breakthroughs required to revolutionize space travel and enable interstellar voyages:

> (1) MASS: Discover new propulsion methods that eliminate or dramatically reduce the need for propellant. This implies discovering fundamentally new ways to create motion, presumably by manipulating inertia, gravity, or by any other interactions between matter, fields, and spacetime.
>
> (2) SPEED: Discover how to attain the ultimate achievable transit speeds to dramatically reduce travel times. This implies discovering a means to move a vehicle at or near the actual maximum speed limit for motion through space or through the motion of spacetime itself (if possible, this means circumventing the light speed limit).
>
> (3) ENERGY: Discover fundamentally new modes of onboard energy generation to power these propulsion devices. This third goal is included since the first two breakthroughs could require breakthroughs in energy generation, and since the physics underlying the propulsion goals is closely linked to energy physics.

3.2 Program Objective

The objective of the NASA Breakthrough Propulsion Physics Program is to produce near-term, credible, and measurable progress toward conquering these three goals. The underlined terms are some of the programmatic features needed to conduct such visionary work in formal institutions such as NASA.

The emphasis on "near-term progress" is because the program's goals are presumably far from fruition while the support for the program is sought in the near-term. It is therefore essential that the long-range goals be broken down into smaller, near-term steps. This is reflected in the Research Priorities discussed later.

Closely related to the need for near-term progress, is the need to *measure* this progress. The program's sponsors want to see progress within the funding cycles. The Research Priority criteria, discussed later, include means to quantify progress.

The emphasis on "credible" is because such long range ambitions are often tainted by non-credible work, or even "pathological science" [33, 34], and since *genuine* progress can only be made with credible work. The challenge to balance credibility (necessary to make genuine progress) with vision (necessary to search beyond known methods) is also addressed in the Research Priorities discussed later. Another aspect of credibility is that this program does not promise to deliver the breakthroughs, but does promise to deliver *progress* toward achieving the breakthroughs. This position is because it is too soon to know if the desired breakthroughs are indeed achievable.

3.3 Collaborative Networking

Historically, pioneering new ideas has often been the jurisdiction of exceptional individuals who not only possessed the vision to realize their creations, but also the determination to weather the setbacks, the skills to translate their ideas into credible proofs-of-concepts, and the ability to make others comprehend their creations. Individuals who posses all these skills at once are rare, but this skill mix often exists in a group of individuals. By providing a means for these individuals to collaborate and share their skill mix to achieve a common goal, pioneering work can proceed without having to wait for the next Goddard or Einstein.

This program was born out of the collaborative networking of individual researchers who explored such topics out of their own interests. This program will continue such collaborative networking. This networking is open to all the NASA centers, government labs, universities, and industries, and credible individuals. Also, this program has recently opened up this collaboration to the international community. Collaborative networking has the following advantages:

- A diverse, multidisciplinary team provides a well rounded and more objective program.

- Expertise and talent are scattered across the world, and are not centralized at a single lab.

- Collaboration boosts credibility.

- Collaboration opens the way for collateral support (where researchers seek support from their host organizations while retaining open information exchange).

- Collaboration allows phased peer reviews, first with the constructive team, then with external reviewers.

The internet is envisioned as the primary mechanism to enable this degree of collaboration and to pool the collective intellect across the world. Two internet sites have already been set up, and a third is envisioned. One site, the "Warp Drive, When?" site (http://www.GRC.nasa.gov/WWW/PAO/warp.htm), is for public education. It describes the difficulties and emerging possibilities of interstellar travel. The second site, the Breakthrough Propulsion Physics Program site (http://www.GRC.nasa.gov/WWW/bpp/), lists the details of this program and its status. The third site is envisioned to be a limited access site. It will contain works in progress, more in-depth annotated bibliographies, and allow on-line discussions. Access will be limited to a "Contributor Network" of researchers selected by the program’s government member steering group. This limited access site has not yet been completed, nor has the process for nominating and selecting Contributor Network members been specified.

Another means to allow collaborative networking is through conferences and workshops. The following is a list of the sessions and workshops held and planned that are related to this topic:

- Feb. 97, Brainstorming Meeting, Austin TX.

- Aug. 97, Breakthrough Propulsion Physics Workshop, Cleveland OH [35].

- Jan. 98, STAIF, 2 sessions, Albuquerque, NM.
- Jun. 98, IAA Symposium, Aosta ITALY.
- Jul. 11, 98, AIAA Joint Propulsion Conference, 1 session, Cleveland, OH.
- Jan. 99, STAIF, 3 sessions, Albuquerque, NM.
- Spring 99, Breakthrough Propulsion Physics Workshop # 2 (in planning).
- Jul. 99, AIAA Joint Propulsion Conference, 1 session, Los Angeles, CA.

3.3 Supporting Research

Presently, this program has only received enough funds to conduct the kick-off workshop and establish the web sites. Efforts are underway to secure funding to formally solicit and support research tasks. In the interim, and for international researchers that are not eligible for US funding, researchers are encouraged to seek funding through their own host organizations. With the precedent of this NASA program, and by using this program's Research Priorities as a guide, it may now be easier for other researchers to secure funding for such visionary work.

Recently the NASA "Small Business Innovative Research (SBIR)" and "Space Technology Transfer Research (STTR)" funding mechanisms have had breakthrough propulsion added to their solicitation topics (http://sbir.gsfc.nasa.gov/). Researchers are encouraged to investigate these alternative funding mechanisms.

Once funded, this program plans to use an annual "NASA Research Announcement" (NRA) to solicit and support research tasks. This solicitation will be open to academia, industry, government labs, and NASA centers. Selection will be via a peer review process using the Research Prioritization Criteria to provide an initial ranking. Because it is too early to focus on a given approach, it is anticipated that multiple, different approaches will be supported from the top ranking candidates. Proposed tasks should be of relatively short duration (1-3yrs), modest cost ($50 to $150K), and traceable to at least one of the three program goals.

4 RESEARCH PRIORITIES

To simultaneously focus emerging sciences toward answering the needs of space travel and to provide a programmatic tool for measuring the relative value and progress of research, this program has established the prioritization criteria listed below. This evaluation system has already gone through three iterations including two trial runs. A derivative of this system is planned as the scoring system for the program's NRA solicitation. The features of the system that are discussed in this report include: (1) near-term focus on long range goals, (2) metrics of progress, and (3) credibility criteria with vision.

4.1 Research Prioritization Criteria List:

This list shows those factors that would be scored to measure the relative value and progress of research. Each of the lettered criteria below would receive a numeric score which would then be combined to arrive at a total score for a given research approach.

• Relevance To Program:

A. Directness (must seek advances in physics that are relevant to propulsion or power).

B. Magnitude of potential gains for goal #1 (mass) + goal #2 (speed) + goal #3 (energy).

• Readiness:

C. Level of progress achieved to date (measured using the scientific method levels).

D. Testability (ease of empirical testing).

[Note: experiments are considered closer than theory to becoming technology].

• Credibility: [Note: these are designed to insure credibility while still being open to visionary ideas]

E. Fits credible data (references **must** be cited).

F. More advantageous to program goals than current approaches (references of competing approaches **must** be cited).

G. Discriminating test suggested.

• Research Task Factors:

> H. Level of progress to be achieved upon completion of task (measured using the scientific method levels).
>
> I. Breadth of work (experiment, theory, and/or comparative study).
>
> J. Triage (will it be done anyway or must this program support it?).
>
> K. Lineage (will it lead to further relevant advancements?).
>
> L. Time required to complete task (reciprocal scoring factor).
>
> M. Funding required (reciprocal scoring factor).
>
> N. Probability of successful task completion (based on credentials and realism of proposal).

4.2 Near-Term Focus to Long-Range Goals

The program's goals are presumably far from fruition while the support for the program is sought in the near-term. To address this paradox it is essential that the long-range goals be broken down into smaller, affordable, near-term steps. Proposals are therefore required to suggest only an incremental task related to the ultimate goals, and are graded inversely to their duration and cost (criteria L and M). Also, from this point of view, "success" is defined as learning more about reaching the breakthrough, rather than actually *achieving* the breakthrough. Negative test results are still results, indicating progress.

4.3 Metrics of Progress

Closely related to the focus on near-term steps, is the need to measure progress. To demonstrate to the program sponsors that progress is being made in the short time-frame of funding cycles, these Prioritization Criteria can be used to quantify progress. By simply taking the difference in score before and after a task is completed, a numerical value of "progress" can be calculated. Since there is no precedent for such a system, these values will only have meaning when *comparing* the progress of different tasks over different years.

One crucial feature inherent in this system is to have a scale to gauge the status of an approach. Patterned after the "Technology Readiness Scale" used to compare engineering status, the Scientific Method has been adapted to address the science that precedes technology. This scale, listed below in order of increasing maturity, are used in criteria C and H. For scoring, a numeric value would be assigned to each level based roughly on an estimate of the relative quantity of work to achieve that level.

- Sci. Method Step Ø: Pre Science - recognizing an opportunity.
- Sci. Method Step 1: Problem Formulated.
- Sci. Method Step 2: Data Collected.
- Sci. Method Step 3: Hypothesis Proposed.
- Sci. Method Step 4: Hypothesis Tested & Results Reported.
- Tech Readiness Level 1: Basic Principles Observed & Reported, same as Sci. Step 4.
- Tech Readiness Level 2: Applications Conceptual Design Formulated.

4.4 Balancing Credibility With Vision

Another challenge of seeking breakthroughs is ensuring credibility without sacrificing openness to new perspectives. This is particularly challenging since genuinely new ideas often extend beyond the established knowledge base, or worse, can *appear* to contradict this base. In other words, a *genuinely* new, credible idea is very likely to *appear* non-credible. Also, it is common when soliciting new ideas to receive a large number of "fringe" submissions that are certainly non-credible. To address this challenge, it is recommended to: (1) concentrate on credible *empirical* data (how nature is observed to work) rather than depending on current theories or paradigms (how nature is *interpreted* to work), (2) compare the new idea's value to existing approaches, (3) ensure that the new idea can be put to a test, and (4) look for the characteristic signs of non-credible science [34]. It should be noted that these credibility criteria do not check if an idea is *correct*, but rather check to see if the idea is credibly constructed and is leading to a correctness test.

Some of the characteristics of non-credible work is that references are not explicitly cited, and that conclusions are made without substantiating the work with supporting evidence. This can be easily checked by requiring that submissions cite credible, peer reviewed, references. References are required for supporting evidence (criteria E), and for comparisons to existing theories (criteria F). Fringe or pathological researchers often do not do this homework. These credibility checks still leave plenty of room for unconventional, visionary ideas.

Empiricism is emphasized over theory as a credibility check since theory is an *interpretation* to explain observations of nature - our current best *perspective*. Theories evolve over time as we gain more understanding about nature, but the empirical observations, the raw data, do not change. For example, the data of the motions of the planets are the same, regardless if one uses the Copernicus theory or the Earth-centered theory to describe the data. When seeking new ideas, it is crucial that they are consistent with credible *data*, but they may entertain new *interpretations* of that data. This emphasis of empiricism over theory is the primary technique to allow credible vision.

To ensure that the idea is oriented toward the goals of the program, and to ensure that the author has done their homework, it is required that the proposal articulate how the new idea compares to existing approaches (criteria F). This not only checks for relevance and to insure reference citations, as mentioned before, but positions the idea to address the next critical criteria; a discriminating test.

A discriminating test (criteria G) is required to focus the work toward the make-or-break issues, and to provide the basis for a credible "correctness" test.

5 AUGUST 1997 WORKSHOP

One of the first major milestones of the program was to convene a workshop with established physicists, government researchers and select innovators to jointly examine the new theories and phenomena in the context of seeking propulsion breakthroughs. This workshop was held on August 12-14, 1997, in Cleveland Ohio [35].

The purpose of the workshop was to understand the fundamental issues and opportunities for new propulsion physics and to foster collaborations amongst researchers. A key deliverable was to assemble a list of candidate research tasks. To achieve this purpose, this workshop featured a plenary sequence of 14 invited presentations about emerging physics with both optimistic and pessimistic viewpoints, 30 poster papers for provoking thought, and 6 parallel breakout sessions for the participants to generate a list of next-step research tasks.

Since this workshop dealt with seeking breakthroughs in science, it asked participants to be *visionary*. Admittedly, these breakthroughs may turn out to be impossible, but progress is not made by conceding defeat. For the sake of promoting progress, participants were asked to entertain, for the duration of the workshop, the notion that these breakthroughs are indeed achievable. Simultaneously, however, this workshop looked for sound and tangible research approaches. Therefore, participants were also asked to be *credible* -- credible progress toward incredible possibilities.

In total, 84 participants attended the workshop, including 26 from industry, 18 from universities, 12 from six government labs, 16 from five NASA centers, and 12 students.

5.1 Invited Presentations

The invited presentations, from established physicists, covered many of the relevant areas of emerging physics. The intent of these presentations was to provide credible overviews of where we stand today in physics and introduce the unknowns and unresolved issues. Below is a list of these presentations in the order that they were presented. Where a related or equivalent work is available, a reference is cited.

(1) L. Krauss (Case Western Reserve Univ.), *"Propellantless Propulsion: The Most Inefficient Way to Fly?"* [36]

(2) H. Puthoff (Inst. for Advanced Studies at Austin), *"Can the Vacuum be Engineered for Spaceflight Applications?: Overview of Theory and Experiments"* [11, 21, 23, 24]

(3) R. Chiao (Univ. of California at Berkeley) & A. Steinberg, *"Quantum Optical Studies of Tunneling Times and Superluminality"* [37]

(4) J. Cramer (Univ. Washington), *"Quantum Nonlocality and Possible Superluminal Effects"* [38]

(5) R. Koczor & D. Noever (MSFC), *"Experiments on the Possible Interaction of Rotating Type II YBCO Ceramic Superconductors and the Local Gravity Field"* [39, 40]

(6) R. Forward (Forward Unlimited), *"Apparent Endless Extraction of Energy from the Vacuum by Cyclic Manipulation of Casimir Cavity Dimensions"* [41, 20]

(7) B. Haisch (Lockheed) & A. Rueda, *"The Zero-Point Field and the NASA Challenge to Create the Space Drive"* [24]

(8) A. Rueda (California State Univ.) & B. Haisch, *"Inertial Mass as Reaction of the Vacuum to Accelerated Motion"* [24]

(9) D. Cole (IBM Microelectronics), *"Calculations on Electromagnetic Zero-Point Contributions to Mass and Perspectives"* [21].

(10) P. Milonni (Los Alamos), *"Casimir Effect: Evidence and Implications"* [18]

(11) H. Yilmaz (Electro-Optics Tech. Ctr.), *"The New Theory of Gravitation and the Fifth Test"* [42]

(12) A. Kheyfets (N. Carolina St. U.) & W. Miller, *"Hyper-Fast Interstellar Travel via Modification of Spacetime Geometry"* [26-29, 43].

(13) F. Tipler, III (Tulane U.), *"Ultrarelativistic Rockets and the Ultimate Future of the Universe"*

(14) G. Miley (U. of Illinois), *"Possible Evidence of Anomalous Energy Effects in H/D-Loaded Solids-- Low Energy Nuclear Reactions"*

5.2 Identifying Next-Step Research Tasks

To generate the list of next-step research tasks, the participants were divided into six breakout groups. Each of the three program goals were addressed by two of the six groups. A facilitator led the group through a process designed to elicit a large number of ideas and then to evolve these ideas into candidate next-step research tasks - tasks that address the immediate questions raised by the emerging physics and the program goals. To be programmatically acceptable, it was desired that these research tasks be short-duration, low-cost, and incremental steps toward the grand goals. Based on the invited presentations, poster papers, and the ideas generated during the breakout sessions, about 80 task ideas were collected.

6 CANDIDATE NEXT-STEP RESEARCH

The following section highlights just some of the approaches that have been suggested to begin the search for propulsion breakthroughs. These are arranged according to the three program goals and highlight the intriguing phenomena and theories, critical issues, and candidate next-step approaches for each program goal. Some of the 48 ideas that were generated during the Austin Texas brainstorming session, and some of the 80 ideas from the August workshop hare covered here. Note that there are many redundancies amongst these 128 ideas, and that most of these have not yet been fully reviewed.

6.1 Toward Eliminating Propellant Mass

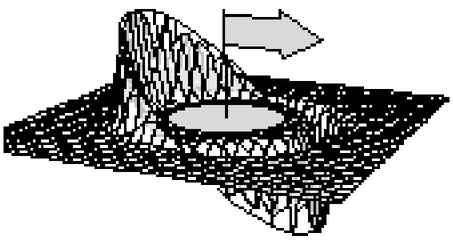
It is known that gravity, electromagnetism and spacetime are coupled phenomena. Evidence includes the bending of light, the red-shifting of light, and the slowing of time in a gravitational field. This coupling is most prominently described by General Relativity [25]. Given this coupling and our technological proficiency for electromagnetics, it has been speculated that it may become possible to use electromagnetic technology to manipulate inertia, gravity, or spacetime to induce propulsive forces [22]. Another phenomena of interest is the Casimir Effect, where closely spaced plates are forced together, presumably by vacuum fluctuations [19]. One explanation is that this force is the net radiation pressure of the virtual vacuum fluctuation photons, where the pressure is greater outside the plates than within, since wavelengths larger than the plate separation are excluded. The force is inversely proportional to the 4th power of the distance. Even though this effect can be explained by various theories [18], the idea that the vacuum might create these forces leads to speculations that an *asymmetric* vacuum effect, if possible, could lead to a propulsive effect [22]. There are many unsolved issues regarding these speculations, including whether these phenomena can lead to controllable net-force effects and whether such effects can be created, even in principle, without violating conservation of momentum and energy [22].

Although it is presently unknown if such propellantless propulsion can be achieved, several theories have emerged that provide additional research paths. It should be noted that all of these theories are too new to have either been confirmed or discounted, but their potential utility warrants consideration. This includes negative mass propulsion [44], theories that suggest that inertia and gravity are affected by vacuum fluctuations [23, 24] and numerous other theories about the coupling between matter, electromagnetism, and spacetime [4, 42, 45-50]. Another recent development, which has yet to be credibly confirmed or discounted, is where anomalous weight changes are observed over spinning superconductors [39].

Regarding candidate next steps, experiments have been suggested to test most of the theories cited above, including the theories linking inertia to vacuum fluctuations [11]. Furthermore, Robert Forward suggested a search for negative mass based on recent astronomical data [51]. Also, experiments at MSFC are continuing to test the claims of weight changes over spinning superconductors [40].

6.2 Toward Achieving the Ultimate Transit Speed

Special Relativity states that the speed of light is an upper limit for the motion of matter through spacetime. Recently, however, theories using the formalism of General Relativity have suggested that this limit can be *circumvented* by altering *spacetime* itself. This includes "wormhole" and "warp drive" theories. A wormhole is a shortcut created through spacetime [26, 27] where a region of spacetime is warped to create a shorter path between two points. A warp drive involves the expansion and contraction of spacetime to propel a region of spacetime faster than light [28]. Figure 2 illustrates the Alcubierre warp drive, showing the opposing regions of expanding and contracting spacetime that propel the center region.



It has also been suggested that the light speed limit may be exceeded if velocities could take on imaginary values [52]. In addition, there are theories for "nonlocality" from Quantum Physics that suggest potentially superluminal effects [38]. These theories not only present challenging physics problems, but are intriguing from the point of view of future space travel. Do these theories represent genuinely possible physical effects, or are they merely mathematical curiosities?

Wormholes, if they exist, may be observable through astronomical searches. The characteristic signature of a negative mass wormhole (possibly a traverseable type) has been specified to aid this search [53]. Regarding possible experiments, it has been suggested to use the strong magnetic fields that are momentarily generated by chemical and nuclear explosions and lasers to test the space-warping effect of magnetic fields [54].

Regarding other faster-than-light possibilities, there have also been some intriguing experimental effects. Photons have been measured to tunnel across a photonic band-gap barrier at 1.7 times the speed of light [37]. Even though the author concludes that *information* did not travel faster than light, the results are intriguing. It has been suggested to conduct similar experiments using matter rather than photons to unambiguously test the *information* transfer rate. In addition, recent experiments of the rest mass of the electron antineutrino have measured an imaginary value [55]. Even though this result is attributed to possible errors, an imaginary mass value could be a signature characteristic of a tachyon (hypothetical faster-than-light particles). It has been suggested to revisit this and other similar data to determine if this can be credibly interpreted as evidence of tachyons. It was also pointed out that other experiments have been suggested to search for evidence of tachyons [56].

The notion of faster-than-light travel evokes many critical issues. Issues include causality violations, the requirement for negative energy, and the requirement for enormous energy densities to create the superluminal effects. Theoretical approaches have been suggested to address these issues, including the use of quantum gravity.

6.3 Toward New Modes of Energy Production

Since the first two breakthroughs could require breakthroughs in energy generation, and since the physics underlying the propulsion goals is closely linked to energy physics, it is also of interest to discover fundamentally new modes of energy generation. The principle phenomena of interest for this category is, again, the vacuum fluctuations. It has been theorized that this energy can be extracted without violating conservation of energy or any thermodynamic laws [20, 21]. It is still unknown if this vacuum energy exists as predicted, how much energy might be available to extract, and what the secondary consequences would be of extracting vacuum energy.

It has been suggested to continue experimental work to study the Casimir effect, not only to address these energy questions, but to explore the more general physics of geometry and temperature effects on the Casimir effect. Techniques have been suggested for using micromechanical technology to study Casimir effects [57]. Not only are micromechanical structures an emerging technology, but the dimensions of such structures are similar to the dimensions required for Casimir effects. Also, should any viable device be engineered, these methods might be adaptable for high-volume manufacturing. On another vein, it has been suggested to continue the study of the sonoluminescence effect and its relation to vacuum fluctuation energy [58].

On a more conventional vein, ideas were raised at the workshop by Tipler and LaPointe for seeking alternative methods of antimatter production.

7 CONCLUSIONS

New theories and laboratory-scale effects have emerged in the scientific literature which provide new approaches to seeking major propulsion breakthroughs. NASA has established a program to begin exploring these possibilities. Since the propulsion goals are presumably far from fruition, a special emphasis of the program is to identify affordable, near-term, and credible research that could make measurable progress toward these propulsion goals. To kick-off the program, collaborative networking, internet communication, and workshops are being used. During a recent workshop, many of these new approaches were reviewed, and several research task ideas were generated for taking the next steps toward propulsion breakthroughs. A NASA Research Announcement has been chosen as the mechanism to solicit and support research, once sufficient funds become available. A peer review system has been drafted to rank these and other future proposals. In the interim, other funding opportunities such as the SBIR and STTR are available.

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Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004

NASA Breakthrough Propulsion Physics Project

COMMON ERRORS

Compiled by: Nicholas Thomas
Summer Student 2002
Aug. 9, 2002

A variety of "breakthrough" propulsion ideas are regularly submitted to the NASA Breakthrough Propulsion Physics Project from amateur researchers, far more than can be assessed. Many of these submissions involve concepts that are already known not to work, even though detailed assessments have not yet been published. Here now, as a service to other would-be submitters and other curious researchers, are examples of commonly submitted ideas that are not propulsion breakthroughs. These examples include a description of why they *appear* to be a breakthrough, and a description of what they really are.

Commonly submitted concepts;

- **Oscillation Thrusters**
- **Gyroscopic Antigravity**
- **Electrostatic Antigravity**

(Others may be added later)

OSCILLATION THRUSTERS

Description

The oscillation thruster, also known as a "sticktion drive," "internal drive," or "slip-stick drive," is a commonly suggested form of space drive that uses the motion of internal masses to create a net thrust. Although there have been many versions proposed, all oscillation thrusters have the following common components:

Chassis to support a system of masses,
Conveyor that moves the masses through an asymmetric cycle,
Power source for the conveyor.

A crucial feature is that these internal masses go through some sort of cyclic motion where the motion in one direction is quicker than in the return direction. One of the most famous oscillation thrusters is the "Dean Drive" described in Patent 2,886,976. Another, more recent, example is Patent 5,685,196 from Richard Foster.

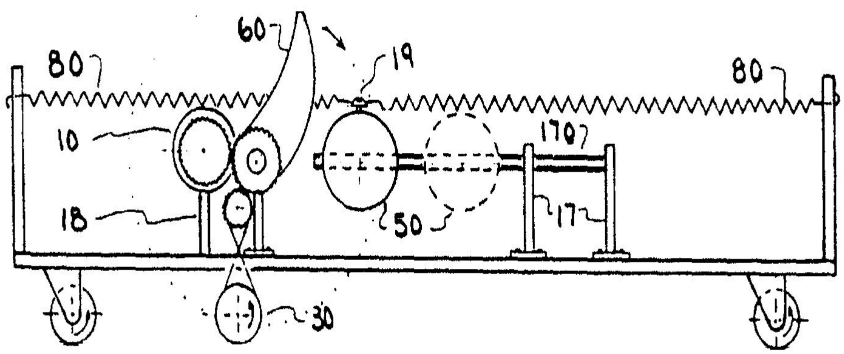
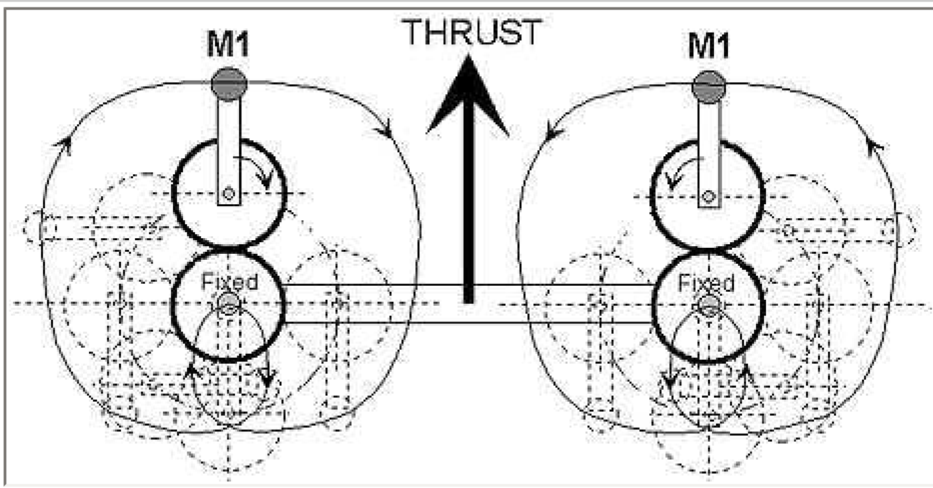


Figure from Foster Patent 5,685,196



Example of gyroscopic oscillation thruster

Source: http://www.geocities.com/CapeCanaveral/Hall/1358/

Why it Looks Like a Breakthrough

As the masses go through their cycle, the whole device will scoot across the floor. One version, placed inside a boat, propelled the boat. Some versions can even work on low-friction surfaces such as ice, or on some air tracks. Thus, the oscillation thruster *appears* to be creating thrust without using propellers or without expelling rocket exhaust. If genuine, such a net thrust would have a significant advantage over conventional rockets, because oscillation thrusters would not require the incredible amount of propellant needed by rockets.

Reflexive Objection

Such devices violate "Conservation of Momentum," a basic law of known physics. It is because of the simplicity and strength of this objection that deeper analyses are seldom published.

Deeper Assessment

These drives can easily be explained with friction - specifically the difference between moving friction and static friction. Recall that the device's internal masses move fast in one direction and slow in the other. When the masses move quickly, the device has enough reaction force to overcome the coefficient of static friction of the floor (or other surface) and the device slides. When the internal masses return slowly in the other direction, the reaction forces are never enough to overcome the coefficient of static friction (sometimes called "sticktion") and it just sticks to the floor. The net effect is that such slip-stick motion causes the device to scoot across the floor. A more fitting test would be to place the device on a level pendulum stand or in free space. During the course of the cycle, the center of mass of the device will always return to its starting position and the whole system would just vibrate around its equilibrium point. No matter how complicated the oscillation thruster, all the forces will cancel each other out over time.

Conclusion

These types of oscillation thrusters can never be used to drive a spacecraft - unless the spacecraft is in contact with a floor. Changing the momentum of an object without exerting force on an outside mass goes against the fundamental law of Conservation of Momentum.

But What If ?...

To keep an open, yet rigorous, mind to the possibility that there has been some overlooked physical phenomena, it would be necessary that any future proposals on these types of devices explicitly address all the conventional objections, and pass a pendulum test. Any test results would have to be rigorous, impartial, and address all possible causes that might lead to a false-positive conclusion. To this day, no one has come forth with any viable theory or experiment that reliably demonstrates that a genuine, external, net thrust can be obtained with one of these devices. If such tests are ever produced, and if a genuine new effect is found, then science will have to be revised, because it would then appear as if such devices were violating Conservation of Momentum.

In the mid 1960s, a "jerk" effect (the time rate change of acceleration) was hypothesized as a new type of force, but no experiments nor physical evidence were ever offered to demonstrate that such a "jerk" exists, and even if it did, whether it could be used to create a space drive. [Davis, "The Fourth Law of Motion", in *Analog Science Fiction, Science Fact,* pp. 83-105, (May 1962).]

GYROSCOPIC ANTIGRAVITY

Description

A gyroscopic thruster is a commonly suggested form of space drive that consists of a system of gyroscopes connected to a central body. Gyroscopic thruster capabilities vary depending on the claims of the particular inventor. Some inventors clam that their drives work by producing an antigravity effect when the gyros are at a high RPM. Other inventors say that their drives are able to transform the gyro's angular momentum into linear momentum for the entire drive. This later group - where a conversion from angular motion into linear thrust are claimed, are really just "oscillation thrusters," discussed previously (and shown above). These drives will just vibrate by changing their internal center of mass, but can't actually create a net force in any direction.

One of the better known "antigravity" claims for gyroscopes, came from Eric Laithwaite. Laithwaite was convinced that gyroscopes had lifting capabilities, and in 1973, he demonstrated his gyro effect to the Royal Institute in London. His demonstration consisted of a singe 50-lb gyro at the end of a rod. He first demonstrated to the Institute that he was unable to lift the device when it was not spinning. But when the gyro was brought up to speed, he was able to lift the gyro above his head. Laithwaite believed that he had discovered a new aspect of physics that would allow a space drive to be made with gyros. The Institute, however, knew that Laithwaite was wrong. The Institute never published his presentation.

Note that this "gyroscopic antigravity" section is not related to the 1992 claims, where it was published that objects appeared to weigh less over superconductors that were spinning and being subjected to RF radiation. This unconfirmed phenomenon deals with entirely different issues than the simplistic gyro inventions discussed here. Also, this section is not related to published observations that gyros have different weights depending on rotation direction, claims that have also not been independently verified. Both these other topics have appeared in the normal scientific literature. For reliable assessments of these claims, please keep abreast of the scientific literature and avoid drawing conclusions from Press articles on these provocative topics.

Note too, that these "gyroscopic antigravity" claims are not related to a very real spacecraft device called a "reaction wheel" or "momentum wheel." These devices, used widely in satellites, control the pointing direction ("attitude") of the satellite.

Why it Looks Like a Breakthrough

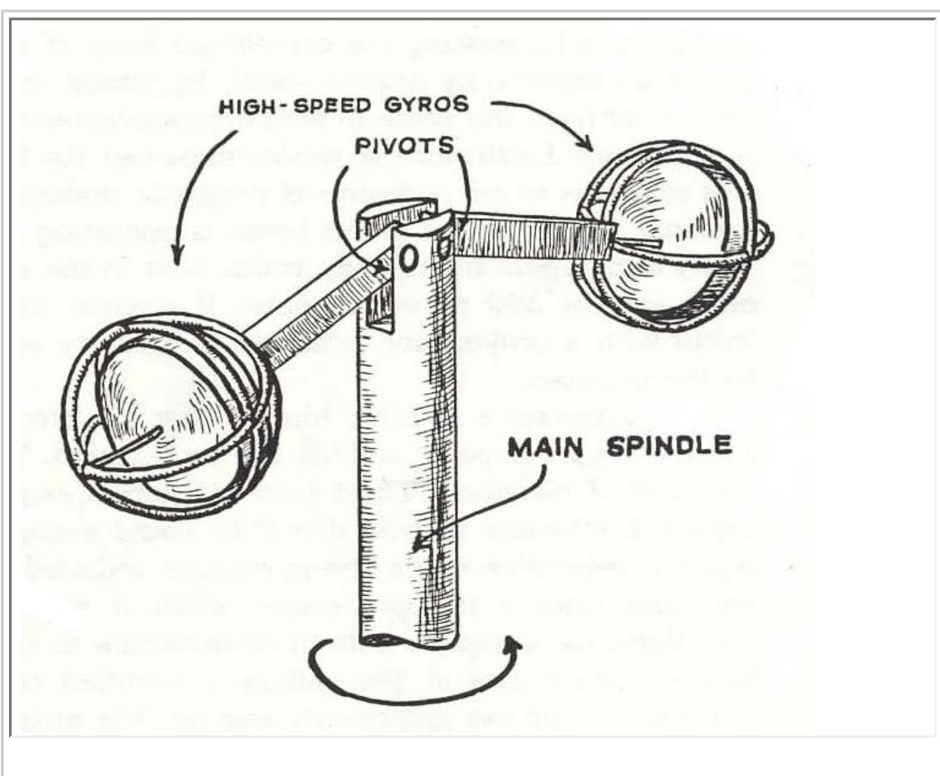
There are several different ways to get the appearance that gyros can defy gravity. The most common is gyroscopic precession. During gyroscopic precession the gyro tilts over and appears as if it might fall down but is stopped by some "unseen" force that holds it up and causes it to rotate around its pivot point.

Reflexive Objection

Such devices violate "Conservation of Momentum," a basic law of known physics. It is because of the simplicity and strength of this objection that deeper analyses are seldom published.

Deeper Assessment

These drives can be explained in terms of "precession." A common school demonstration of gyroscopic precession involves placing a tilted, spinning gyro on a table. Rather than tipping over the rest of the way, the whole gyro assembly, instead, begins to rotate. This is a result of "Conservation of Angular Momentum" as gravity is pulling down on the gyro. What Laithwaite showed to the Institute was not a way of making antigravity, but was a form of forced precession. Examine the figure below. Laithwaite would force his gyro to rotate (arrow at base of "main spindle"), and as a result, the whole gyro and rod assembly would turn upward (arms pivoting up at "pivots"). An important detail is that the force is not "lifting" the gyro, but is a "torque" that is twisting the gyro/rod assembly upward about the pivot point of the gyro's arm.



Example of a Laithwaite device
Source: Childress, *The Anti-Gravity Handbook*, Adventures Unlimited Press, Stelle, IL, 1988.

Although there are other claims that spinning gyros can affect gravity, including legitimate treatments from General Relativity, these are not space drive effects. Consider for example, if it were possible to produce a gyro that spun at relativistic speeds. The Special Theory of Relativity states that the mass of the gyro will increase instead of decreasing. This is not an antigravity effect.

Conclusion

Gyroscopes can never be used to push a spacecraft, but gyroscopes, in the form of reaction wheels, can be used to change the angular orientation of a spacecraft. Changing the linear momentum of an object without exerting force on an outside mass, goes against the fundamental law of Conservation of Momentum.

But What If ?...

To keep an open, yet rigorous, mind to the possibility that there has been some overlooked physical phenomena, it would be necessary that any future proposals on these types of devices explicitly address all the conventional objections, and pass a pendulum test. Any test results would have to be rigorous, impartial, and address all possible causes that might lead to a false-positive conclusion. To this day, no one has come forth with any viable theory or experiment that reliably demonstrates a genuine, external, net thrust can be obtained with one of these devices. If such tests are ever produced, and if a genuine new effect is found, then science will have to be revised, because it would then appear as if such devices were violating Conservation of Momentum.

ELECTROSTATIC ANTIGRAVITY

Description

Electrostatic antigravity, which originated at least as early as the version called the "Biefeld-Brown" effect, is a force-producing effect resulting from placing high voltage across unusually shaped capacitors. There are several variations of this half-century-old idea, devices with such names as "Lifters," "Asymmetrical Capacitors," "Electrogravitics," or "Electrokinetics." The shapes and sizes of the capacitors vary, but they are typically large enough to be easily observed (on the order of centimeters in size). Sometimes the capacitors are shaped to look like flying saucers. Other times they are arranged as rings and disks. One of the most recent versions, the "Lifter," is usually a triangular arrangement of three capacitors, where the two electrodes of the capacitors are placed one above the other. The upper electrode is a simple wire. The lower electrode is a plate of aluminum foil, oriented in an upright position. The whole assembly is constructed out of balsa wood poles, aluminum foil, and copper wire.

Why it Looks Like a Breakthrough

These devices are relatively easy to construct and operate. They have no moving parts. When charged up to high voltage (normally around 40 kV, and less then 1 mA of current), the light-weight versions of these devices can lift off the ground and levitate. The power supply, however, remains on the ground and the power is delivered with extension wires. Since such levitation is seldom seen with everyday devices, many people assume that some antigravity effect is at work.

Reflexive Objection & Counter Arguments

For those who are familiar with high voltage effects, such devices are assumed to be simply operating from ion wind. Ion wind is an air flow that is created by the ions that move from one capacitor electrode to the other. The devices are pushed up by the reaction forces from this downward motion of the surrounding air. Even in a vacuum, there can still be enough ion motion or corona discharge to cause counter forces. If the devices were operating by something other than ion wind, then such devices would appear to violate "Conservation of Momentum," a basic law of known physics.

Most advocates for these electrostatic antigravity devices admit that ion wind is present, but claim that the observed forces are too large to be accounted for by just ion wind.

Deeper Assessments

Unlike the gyro and oscillation devices described earlier, these electrostatic antigravity devices are much more difficult to rigorously analyze. It is very difficult to isolate all spurious causes that might lead to a false positive, even when these devices are operated in a vacuum. Fortunately, reports have been published that describe more rigorous experimental techniques. Here are three examples:

Talley, R .L., (Veritay Technology, Inc. East Amherst NY), **Twenty First Century Propulsion Concept**, PLTR-91-3009, Final Report for the period Feb 89 to July 90, on Contract FO4611-89-C-0023, Phillips Laboratory, Air Force Systems Command, Edwards AFB, CA 93523-5000, (1991).
Tajmar, M., "**Experimental Investigation of 5-D Divergent Currents as a Gravity-Electromagnetism Coupling Concept**", in *Proceedings of the Space Technology and Applications International Forum (STAIF-2000)*, El-Genk editor, AIP Conference Proceedings 504, American Institute of Physics, New York, pp. 998-1003, (2000).
Tajmar, M., "**The Biefeld-Brown Effect: Missinterpretation of Corona Wind Phenomena**," *AIAA Journal*, Vol **42**, pp 315-318 (2004)

All these studies, examining different versions and using different techniques, found that there were no extra forces produced. These devices are not antigravity devices.

Conclusion

Their is no new force at work here. All evidence to date suggests that all the thrust created with these devices comes from an easily produced phenomena, ion wind. There is no evidence to suggest that any type of antigravity effect is responsible for the thrust. None of the proponents of these devices have reported any experimental evidence in any peer-reviewed publications to support their claims that a new force is being demonstrated.

Regardless of the cause of the effect, there is the question of utility. So far, such devices cannot lift much mass (typically, they produce about a few-thousandths of a Newton, while consuming around 20 to over 100 Watts). None have been able to levitate their power supply, let alone an additional payload. This limits their utility when compared to alternative forms of aircraft propulsion. Regarding their application for spacecraft, their in-vacuum performance has not yet been reliably measured. If and when such tests are conducted, their performance can then be compared to other existing forms of electric propulsion, such as Ion Propulsion.

Because it is easy to build and operate one of these devices, however, its most fitting utility may be as an instructional tool for demonstrating the dramatic phenomenon of ion wind.

But What If ?...

There are, however, still some unresolved issues. Specifically, during the Talley tests (referenced above), anomalous forces were observed during the on/off transients -- anomalies that were never resolved. To keep an open, yet rigorous, mind to the possibility that there has been some overlooked physical phenomena, it would be necessary that any future proposals on these types of devices explicitly address all the conventional objections, and pass rigorous experimental tests. Any test results would have to be impartial and address all possible causes that might lead to a false-positive conclusion. To this day, no one has come forth with any reliable experimental evidence that demonstrates that a genuine, external, net thrust can be obtained with one of these devices. If such tests are ever produced, and if a genuine new effect is found, then science will have to be revised, because it would then appear as if such devices were violating Conservation of Momentum.

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Last update: May 13, 2004

SPECIAL CHALLENGES

If you wish to support the search for propulsion breakthroughs, please read this section

Exploring the edge of knowledge for profound discoveries evokes special challenges. In addition to the normal challenges of scientific research, i.e. figuring out how nature truly works - the provocative character of grand challenges can encumber such research. First, by pursuing truly profound improvements in the human condition, the stakes are higher and accordingly emotions run higher. Second, by operating on the genuine edge of knowledge, instead of exploring routine refinements of established knowledge, one encounters controversial ideas. This combination of heightened emotions and controversy can taint the productive discourse of scientific study. A typical example is how both skeptics and optimists can sometimes jump to conflicting conclusions and, in their zeal, fail to communicate in the dispassionate and impartial style needed to rigorously identify, test, and resolve the real issues.

Ironically, most of the difficulty encountered by the BPP Project has come from unofficial proponents, rather than from skeptics. Virtually all the skeptics have been constructive. Most skeptics have clearly identified issues and unsolved physics that present challenges for discovering propulsion breakthroughs. By identifying such specifics, research objectives are defined and refined.

The bulk of difficulties have come from enthusiasts whose well-meaning actions have actually impeded progress. Because such problems are increasing, this section has been added to the public web site to explicitly address this challenge. It is hoped, by explaining this situation, that those interested in this Project will better understand the impact of their actions. Below, links are provided to short descriptions of the most common, recurring events that impede progress. Where appropriate, examples are given to help readers appreciate the difficulties. And finally, guidance is provided for more constructive actions.

Special Challenges - How to Help:

- Excessive correspondence overwhelms BPP resources - When and how to contact BPP.
- Making claims of breakthroughs without peer review taints the subject - How to publish results and sustain commercial advantage.
- Unpublished research allows costly dead-ends to be repeated - How to publish results.
- Supporting research without assessing options typically results in repeated failures - Investors check with BPP Consortium.

Thank you for your attention and support.

[Back to the BPP Project Home Page]

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Last update: May 13, 2004

SPECIAL CHALLENGES

- CORRESPONDENCE -

BACKGROUND:

Due to the high-profile and provocative nature of the Breakthrough Propulsion Physics Project, much more correspondence is received than can be fully answered. Over a two-year period, the BPP Project received well over two thousand messages in addition to the expected correspondence. Before sending correspondence, please check our FAQ and check the list below of standard questions (and links to standard replies).

Statistics on Unsolicited Correspondence:

(data averaged over 2000 and 2001, compiled January 2002)

TOTAL RECEIVED PER YEAR (average, approximate)	1000
Researchers with peer-reviewed data or inquires about proposing research • "How do I submit a research proposal or a technical paper?" • "Are there any jobs with BPP?"	32%
Information requests • "Please help me with my homework." • "Please tell me more about..." • "Have you ever heard of..?"	30%

Amateur researchers wanting assistance to evaluate or advance their ideas • "I have a breakthrough I want to tell you about." • "I have an idea to offer for your review." • "Please help me with my idea."	22%
"Lunatic Fringe" (idea submissions displaying delusions of grandeur or paranoia) [excerpts]	9%
News of other events or workshops	4%
Press interviews	2%
Requests for a BPP speaker at public events	1%

APPROPRIATE CIRCUMSTANCES FOR CONTACTING BPP
-- Contact point not presently available --:

- Responding to a call for papers or proposals.
- Notifying BPP before publishing relevant results.*
- Notifying BPP of other relevant publications / events.*
- Offering assistance in the review of BPP-related works.
- Considering investing in BPP research.
- Requesting a press interview.
- Requesting a BPP public speaker.

* To make this constructive, only alert us to reports that are in peer review literature, and provide the full citation information. To be additionally helpful, provide a one sentence to one paragraph summary of the key point of the publication and why it might be of interest to the BPP Project.

[Back to the "Special Challenges" overview Page]
[Back to the BPP Project Home Page]

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Last update: May 13, 2004

SPECIAL CHALLENGES

--- Excerpts from the "Lunatic Fringe" and hopeless amateurs ---

(idea submissions displaying delusions of grandeur or paranoia)

These samples are offered to illustrate one of the disappointing types of correspondences frequently received by the BPP Project. Although these offerings can seem entertaining at first, they become taxing after receiving dozens of them. Based on the advice of a psychologist, no answer is sent in response to such submissions. No correspondence could provide the type of help needed, and any response would only encourage more of this nonproductive behavior.

To make these excerpts less offensive, only humorous and unthreatening examples are shown. The names of the senders and any other traceable data has been removed from these excerpts.

Typical opening lines:

- "I'm not a scientist, but…"
- "I'm a retired engineer, and now that I have extra time, I have this theory …"
- "Since I'm in prison, I've had time to think about my theories…"
- "I've seen a UFO and here's how it works.."

Recall the quote from Edison that: "Invention is 1% inspiration and 99% perspiration." Frequently individuals submit their "inspirations" with the desire that NASA complete the other 99% of the work (and anoint the submitters with accolades). A shorthand phrase for these individuals is "one-percenters".

QUOTES & ANECDOTES:

- From a man doing time in a correctional institute, who wrote to express his interest in considering a career in physics: “You see, I have always had a love for science, Life Science at first, then went through a chemistry phase which landed me where I am currently positioned.”

- From a guy who sends NASA approximately 1 letter every month, all in capital letters, and connected with commas between every word (Most commas omitted for clarity): "This is my invention for metaphysical gears for the transmission of future spaceships. This secret I got from the crystal ray which I devised from the circle, the plane, and the center, long ago. The FBI in Wash D.C. have my crystal ray work." A more recent submission from the same individual said: “You, NASA, see I am an American visionary and the son of man and I hear voices, seriously, from beyond the grave and the spirit world on high, and I ran into your own house, and they confirmed with conquest in myself and faulted, so I told them I would not sell you these engines and faulted myself….”

- While giving a lecture to a space society club in Huntsville, Alabama, one of the audience members (NOT one of the NASA employees) offered his help. He said he'd been "Channeling" with Einstein and Einstein had made more progress on his unified field theories.

- From a phone call: "I am sure my theory is credible, because ever since I thought of it, I am visited each morning by aliens in my bedroom."

- From a web discussion group: “Yep, I have just returned from an interesting experience. On October 21, I was taken at gunpoint aboard a US government secret levitator craft and taken to the far side of the moon. It was really emotional looking down on the earth from space from high-orbit. Moonbase Yellow was nothing spectacular once you got past the high-tech transport and defense systems. Their labs were cool, though, and I think that some of them were clones, or else people changed their clothes a lot. The craft was a neat ride and made cool noises. I could tell that acceleration forces were appreciably damped. I had a window seat, and could tell that there were no lights on the outside. The trip to the moon took a little over two hours. Anyway, they just wanted to sort of guide my research if you know what I mean. Horton pointed me in some interesting directions. Did you know that if you make iron or nickel clusters small enough, the clusters' surface forces are such that that the clusters' melting point exceeds the vitrification temperature? I thought pure iron glass might be cool to someone. Maybe you guys knew this already... I don't really know if I can trust Horton. Peace.“ [Note that he claimed to enjoy the view of the Earth from the ***far*** side of the moon].

- Yes, this is a direct quote from an email: “Rockets??? Ha! Ha! Ha! NASA will never come up with the Break Through Propulsion System, least they swipe it leading us into Interstellar Travels because they are still applying a Brute Force Concept, rather it will come from a lone inventor. …… Tee! Hee! Hee! ……. And to think my concept was rejected on the basics that it goes against fundamental physics you, NASA and the rest of the Academic world do not understand the basic principles of AC Radio-Gravitics let a lone that nature is superconductive. …I'll permit you to look at my discoveries If you have the balls that is to open your closed mind!”

- Another email excerpt: "To tell you the truth Marc, I'm a pot smoking mushroom munching high school dropout and I'm qualified to do two things; wash dishes and invent shit. … I've got other inventions too - an electrochemical computer, ultrasonic foaming process, magnepulsion generator, solid state over-unity device, various concept vehicles, centrifugal antigravity drives, and butlloads of more practical inventions."

- “I'm the purple depths of the ocean which is don't forget the purple star gem exploding at seven miles a second at the command of I want to turn into a giantess or imploding at the command of ill leave it by itself I am a blue crested wave under the moon which is hanriffic or hanalriffic and hanalulriffic by me I am an ancient emerald forest or tree your pick which is what I like to call watching bark peel off a tree and sticking it on the back of their neck casting a massmorph spell and watching them rut into a tree or freaking out and turning their head which way I am a yellow tear from the sun which is gnidolpxe star gem which is still the color of qurbol the command is ssetnaig e otni nrut ot tnaw I am an orange pumpkin in the field which kind of reminds me of the phoenix oh I meandsun laughing at me just call that a little Irish schizophrenic humor and finally I am a flaming door which is all part of the right of the active door which most of came from the 21 lessons of Merlin a study of druid lore and magic which is preferable to the bible did I hear the words jungle sanctuary or was that essences…"

- From a man who may have forgotten to clean his video camera lens, and shares his monitary desires: "…there was the image…in the shape of a head I decided to start experimenting around the rest of my home and other homes. With each experiment, the results were the same…Each had 2 eye sockets and you can see their mouths moving but you can't hear anything …They all looked really hateful. Crazy I know, but everyone I have shown, has said the same thing. My motive for this letter is simple, I know I have found something very, very special and I want paid lots and lots of money for it. To be exact, I want millions."

- And here is an entirely different attitude about money: "'Astro-travel - free of charge'. You blithering idiots. To travel the realms of space free of charge is not possible. All members of the public need a toilet. I, Jeff, being educated, charge you all not to expel the fumes of the charge I indict you all with when you enter the correct room of learning, to which I present you all with."

- From the inventor of a claimed "tachyonic transceiver:" "If we could just get copies of papers sent to [list of agencies, and a person down in Florida], then we would have it all, and could get together 3 or 4 teams to work on this… as we do not want to fall behind the rest of the world…. Also, I would appreciate a car and salary such that I could meet with the teams as they assemble the transceiver as I would hope to continue to create enthusiasm for the project."

- Here is another job seeker: "Since there are so many clues around, the double alpha geometry will become known. By myself and others. Its' a beautiful by-product from the geometrical evolution of collison, friction, and the state of motion. As you know I've been having one hell of a time with 'E'…..I may be changing occupations. Since I never became "socialized" I learned a lot about people, and myself, by driving a cab. Now I must have access to some tools. So I may go to work for a generator repair shop."

- From a man willing to devote himself to the good of science: "Just call me a chronic dreamer and a glutton for the unknown. Do you need a Guinea Pig for any experiments. I may be [your] man."

- There are those that assume that Star Trek is real. NASA received over 10 pages, typed, quoting from the Star Fleet technical Manual.

- "I entered the new information and data in a mind-altering albeit drug-free trance in which I had a five-month conversation with God."

- It is unknown why this message was sent to NASA. This text is a paraphrase of the submission: There was a young man who claimed that all of a sudden, he could not find his head. He was a headless being and he didn't know what happened. He went and asked his mother why he was born without a head, and she said, "it's there on your shoulders," and he looked in the mirror, and lo and behold, there it was!

- From a short and sweet email (if you'll allow the pun), the entire message was: "Hi, I've heard of warp drive. I love strawberries."

- This message followed a NASA lecture to a 5th grade class: "I always ask my parents questions about space and they never know. My dad takes guesses and he is always wrong and when I say the answer, my mom says "O, I knew that, I was just wanting to hear what Dad said!"

- From a letter that included a CAD rendering of a wormhole experience (appears as a dark gray circle within a light gray rectangle): "Not really knowing the origins of what I saw, (see attached) I can truly say that wormholes are a reality, although short lived. The image that I am sending you is of a Non-Linear Space-Time Displacement Event, a wormhole by any other name. It found its way into my apartment, several times, to remove from my existance, some personal object, only to return the object to my existance at a later time and in a different location. Truth is stranger than fiction. This is truth. The grey area out side the hole is my living room carpet, the striped "ring" is the interface, the whitish center is the sidewalk outside my apartment at the time of reentry into my existance. The grey carpet and the sidewalk were/are 10 feet, 36hr. apart. I hope that you will take a look at the image. It is a rendered CAD model of what I saw."

- In 2001, the BPP Project Document Control Specialist received a letter from a medical doctor from Michigan, with an enclosed $50.00 check for her "time & trouble" in getting Marc Millis to review his paper. The check was returned to the sender.

- These next quotes are from a grocery store clerk who sends in pictures (and sometimes the cardboard devices themselves) which are claimed to induce "space transparency worm holes." One photo shows him holding a box with the caption: "you can tell that his device [cardboard box[is working because the lines in the pavement are showing through in front of my pants." In the black & white photo, the black lines and his black pants are indeed indistinguishable. A further quote reflecting a touch of paranoia: "A few years ago I was talking to Mr. [-snip-] who said our conversation was being traced and a black helicopter fly over would possibly occur tomorrow…. Next day a black helicopter flyer with a white triangle and an instrument in the middle of the white triangle flew over. If this was a Pledian ship mimicking a Delta Force helicopter, they could have done their transparency recording of my apartment…perhaps the technology has characters mimicking the counselors or rulers…called Super Beings, from the Pleidian system." And finally, a recent submission states: "A cardboard box used as a stand for the coils after the Mirrors Array was tried lost 34% of its weight and then disappeared. We do not know if this was teleportation or if someone threw it out."

These are just some samples from dozens of similar submissions.

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Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004

RECENT BPP ACTIVITY REPORTS

(Most recent at top of list)

May 13, 2004
A summary of the findings of 16 research tasks related to Breakthrough Propulsion Physics was recently published as NASA TM-2004-213082. The author, Marc Millis, will be presenting this summary at the 6th NASA/DoD Conference on Evolvable Hardware in Seattle, WA, on June 24-26, 2004. Of the 16 tasks (8 of which were supported by the BPP Project), 6 were found not to be viable, 4 are likely to have sequels, and 6 remain unresolved. More research approaches are expected to emerge.

March 17, 2004
The thirteenth peer-reviewed journal article resulting from the now deferred Breakthrough Propulsion Physics (BPP) Project was recently published. Specifically, Jordon Maclay of Quantum Fields LLC, and Robert Forward (since deceased), demonstrated that it is theoretically possible to induce net propulsive forces from interactions with the quantum vacuum energy of space. This would constitute a form of propellantless propulsion. Although the magnitude of the effect is impractically small at this stage, this work at least opens the door to the possibility. Also, based on Maclay's prior work, this vacuum energy can be experimentally explored with MicroElectroMechanical (MEM) technology. The article, entitled "A Gedanken Spacecraft that Operates Using the Quantum Vacuum (Dynamic Casimir Effect)" appears in volume 34 (March 2004) of Foundations of Physics, pages 477-500.

March 3, 2004
Aviation Week and Space Technology Magazine reported on March 1, 2004: "At least two large aerospace companies and one U.S. Defense Dept. agency are betting that 'zero point energy' could be the next breakthrough in aerospace vehicle propulsion, and are backing those bets with seed money for ZPE research." (pg. 50-53) This is one of the key topics addressed by the Breakthrough Propulsion Physics (BPP) Project. Marc Millis was quoted in the article: "We need to make sure that we're not extending our claims beyond what the evidence points us to today. To be impartial, I'd say that we're not on the verge of grandiose breakthroughs, but we have another embryonic field opening up to us."

February 11, 2004
Using materials supplied by the Breakthrough Propulsion Physics (BPP) Project, Dr. Martin Tajmar, of Seibersdorf Research, gave a lecture to Masters students at the International Space University, in Strasbourg France, on February 11, 2004. Follow-up lectures are planned, and Dr. Tajmar is considering developing an extended version for teaching at his host Institute for Lightweight Structures and Aerospace Engineering, in Vienna Austria.

November 26, 2003
The Breakthrough Propulsion Physics (BPP) Project continues to garner positive press for NASA. The most recent article, by Leonard David, starts by citing the Aerospace Commission's recommendation for supporting long-term research that looks "beyond our current understanding of physical laws," and then goes on to describe the BPP Project. The article continues with more near-term far-out stuff such as antimatter and laser sails: http://space.com/businesstechnology/technology/fof_physics_031126-1.html
Since the founding of the BPP Project in 1996, there have been over 109 positive press stories on this effort, including a supportive editorial in the New York Times on Feb 5, 2003, in the wake of the Columbia accident.

November 12, 2003
The twelfth peer-reviewed journal article resulting from the now deferred Breakthrough Propulsion Physics (BPP) Project was recently published. Specifically, Peter Milonni of Los Alamos, and Jordon Maclay of Quantum Fields LLC, present an assessment of the affects of negative refraction index materials on radiated recoil, the Doppler effect, and the rates of spontaneous and stimulated radiation. The article, "Quantized-field description of light in negative-index media" appears in volume 228 of Optical Communications, pages 161-165.

Oct 6, 2003
Even while unfunded, the Breakthrough Propulsion Physics (BPP) Project continues to garner positive press for NASA. The most recent was a two-part article by J. Pethokoukis in the Science and Technical section of U.S. News, posted at usnews.com (Oct 1 & 2). Marc Millis, founder of the BPP Project, was asked to respond to comments by Presidential candidate, Wesley Clark, where Clark was quoted as believing that faster-than-light travel might one-day be possible. The two articles are archived at:
http://www.usnews.com/usnews/nycu/tech/nextnews/archive/next031001.htm
http://www.usnews.com/usnews/nycu/tech/nextnews/archive/next031002.htm

August 8, 2003
The August issue of Cleveland Magazine featured a 10-page article about the work done at NASA-Glenn. The following 4 researchers and their work were highlighted: Mike Patterson – Ion Propulsion; Geoff Landis – Photovoltaics for Mars and Venus exploration; Rafat Ansari – Dynamic Light Scattering for fluid physics and medical diagnostics; and Marc Millis – Breakthrough Propulsion Physics.

July 24, 2003
Marc Millis presented a 1-hour invited oral lecture at the 39th annual Joint Propulsion Conference about the status of the Breakthrough Propulsion Physics (BPP) Project, on Wednesday, July 23. This presentation, entitled "Requiem or Revival?" covered an overview of the technical findings of the Project, overviews of related work sponsored by others (incl. British Aerospace Systems, European Space Agency, and privately funded efforts), and the management lessons learned from running the project from 1996 to 2002. About 100 people attended the presentation. Also, 4 other papers related to BPP were presented in that session, and 2 other 1-hour BPP papers were presented in a Monday evening session. Based on later feedback and on the caliber of questions from the audience, the rigor and comprehension of this topic is improving.

July 17, 2003
Dr. Hector Brito, of the Inst. Univ. Aeronautico of Argentina, visited GRC during the week of July 14-18 so that NASA could perform cursory tests of his electromagnetic inertial thrusting device. This device falls within the scope of the Breakthrough Propulsion Physics (BPP) Project since its operation is based on unresolved physics that might be suitable for propulsion. Specifically, the device takes advantage of the Minkowsky interpretation of electromagnetic momentum (as opposed to the more common Abraham interpretation) to create net thrust. The distinction between these interpretations, which dates back to 1909, is whether the permittivity of the surrounding media affects the momentum. In Minkowsky's view there is an effect. In vacuum, the interpretations are identical, which is why the issue is seldom revisited. Data analysis of the device testing is still underway. The US Air Force's European Office of Aerospace Research and Development sponsored this visit.

May 12, 2003
Marc Millis (5870) presented an overview of NASA's Breakthrough Propulsion Physics (BPP) Project at the May 6-9, invitation-only, workshop on "High Frequency Gravitational Waves," sponsored by the DoD. In contrast to the large science programs to develop detectors for large wavelength gravitational waves

(LIGO and LISA), this workshop examined the emerging physics of high-frequency gravitational waves in the context of seeking breakthrough technology for communication and imaging. The workshop contrasted a variety of theoretical and experimental techniques to conclude that there are several reasonable research opportunities, but that any technological applications were a long way from fruition. An informal research network and Foundation funding will be sought to further explore these options, headed by a retired university president, Robert M. L. Baker.

March 26, 2003
In a recent book about pioneers in spaceflight, entitled; “Spaceflight: Crossing the Last Frontier,” which features sections on Goddard, von Braun, and others, a description of the Breakthrough Propulsion Physics Project, complete with a photo of Marc Millis, closes the last chapter. This 2002 book is authored by Jason Richie, and is published by The Oliver Press, Inc, Minneapolis, MN.

March 12, 2003
A full-page article appeared in the March 12, 2003, Los Angeles Times about the Breakthrough Propulsion Physics work of Marc Millis, including a photo of Millis. The author was P. J. Huffstutter.

March 7, 2003
On February 25, representatives of West Virginia’s Institute for Scientific Research (ISR) visited NASA GRC to discuss their Congressionally earmarked tasks related to the NASA Breakthrough Propulsion Physics (BPP) Project. As reported on July 19, 2002, ISR will not be able to complete the original task to investigate the propulsive implications of the Heaviside force. Furthermore now, ISR terminated their subcontract to the University of West Virginia for the torsional experiment of the Heaviside force, due to lack of progress. Instead, they are now redirecting their effort to perform an analytical experiment of the Feynman Disk Paradox from the Abraham / Minkowski Perspective, which addresses more fundamental issues of the original Heaviside claims. Also at this meeting, ISR briefed NASA on their progress on testing the MSFC’s patented "Asymmetrical Capacitor Thruster (ACT)," including the BPP Project’s request to also cover the other unsubstantiated claims of "lectrostatic antigravity."

February 25, 2003
In the February 18 issue of SpaceNews, there is an article about the NASA Breakthrough Propulsion Physics Project and the end of its funding. The article, by Ben Iannotta, is on page 18.

February 5, 2003
The NASA Breakthrough Propulsion Physics Project was cited in a complimentary manner in the New York Times, in the article, "Onward and Outward," by Thomas Mallon. The article was in the Editorial / Op-Ed section.

January 31, 2003
The BPP Project Management was informed, from Code-R "Energetics" (which is under "Enabling Concepts and Technologies"), that no Fiscal Year 2003 funds are available to sustain the BPP Project while waiting for a firm "yes/no" decision.

January 8, 2003
Marc Millis gave a 3-hour lecture on "The NASA Breakthrough Propulsion Physics Project: Methods in Advanced Research," as part of the AIAA's Fast-Track Tutorial series, conducted during the 2003 Aerospace Sciences Meeting in Reno, Nevada, January 5. This tutorial, invited by the Nuclear and Future Flight Propulsion Technical Committee, presents an overview of the Breakthrough Propulsion Physics Project as a template to discuss methods for initiating and conducting advanced high-risk/high-payoff research programs.

November 26, 2002
Encouraging words for long-range basic research are prominent in the recently released Aerospace Commission Report, lead by Robert S. Walker (http://clients.biznews24.com/aerospace/). First, quoting from the Executive summary: "Achieve Breakthroughs in Propulsion and Space Power." Next, quoting from Chapter 9, which itself is entirely devoted to requesting increased support for Basic Aerospace Research: "New propulsion concepts based on breakthrough energy sources, ... could result in a new propulsion paradigm that will revolutionize space transportation." And: "In the longer-term, breakthrough energy sources that go beyond our current understanding of physical laws, ... must be credibly investigated in order for us to practically pursue human exploration of the solar system and beyond."

November 22, 2002
On the NASA-sponsored task to Dr. Jordan Maclay to investigate Quantum Vacuum Energy using Micro-Electro-Mechanical (MEM) structures, 2 more papers have been submitted to Journals; one dealing with quantum effect in negative refractive media, and the other on the effects from finite conductivity in Casimir (vacuum energy) cavities. This brings the total publication count so far on this task to 9 papers, 5 of which have been published in peer-reviewed journals.

November 21, 2002
Educational Outreach: On October 8th, Marc Millis gave a videoconference presentation about the difficulties and approaches to interstellar travel to 3 high-school physics classes in Michigan: Stephenson High School, Mason-Lake Oceana High School (Scottville), and Sterling Heights High School. This event was coordinated by Glenn's RSIS programming team.

November 11, 2002
Educational Outreach: On November 15th, Marc Millis gave a videoconference presentation about the difficulties and approaches to interstellar travel to five high-school physics classes from Jackson, Mississippi. This event was requested by Stennis Space Center, and coordinated by Glenn's RSIS programming team and the Mississippi Interactive Video Network.

September 24, 2002
On Sept 13, representatives of West Virginia’s Institute for Scientific Research (ISR) visited NASA GRC to discuss the two tasks underway for the NASA Breakthrough Propulsion Physics (BPP) Project. As reported on July 19, 2002, ISR will not be able to complete the originally proposed, Congressionally earmarked task to investigate the propulsive implications of the Heaviside force. This meeting was to confirm the redirection of effort into these two efforts: (1) Completing the subcontracted WVU replication of the torsional experiment of Heaviside forces, and (2) expanding their tests of MSFC’s patented "Asymmetrical Capacitor Thruster (ACT)" to cover the other related claims of “electrostatic antigravity.” IRS requested, and Millis granted, an extension until March 2003 to finish these tasks. The MSFC ACT tests have been designed and a test facility is being sought. After completion of the ACT tests, the other variants of the half-century old “Biefeld-Brown” effect will then be tested. These include the “Antigravity Lifter” claims similar to that of Tim Ventura, a classic Biefeld-Brown configuration, and at least one other variant.

Air Force Academy & BPP: Following up on the May 2002 discussions with the US Air Force Academy (USAFA) about using Cadet “educational projects” as venue for low-cost, independent assessments of Breakthrough Propulsion Physics (BPP) claims, a GRC summer student submitted project suggestions and sample homework problems to a faculty member of the USAFA. Cadets are already working on a variety of experiments related to advanced propulsion.

Progress on “Gravity Shielding” hardware: By invitation of the MSFC manager of this task, Marc Millis and Paul Raitano of GRC visited the Columbus, Ohio firm, Superconductor Components, Inc. (SCI) on September 4, 2002, to view SCI's progress toward replicating the hardware of the heavily-publicized Podkletnov's "Gravity Shielding" claims. This work is sponsored by a Phase-II SBIR through MSFC. The specially configured large (12-inch) superconductor disks have now been successfully manufactured, and much of the supporting test hardware has been built. During the Sept 4 tests, the disk successfully levitated and could be mechanically rotated at slow speeds. What still remains, is to replicate the means to rotate the disk at high RPM (10,000) and to pump in Radio Frequency (RF) energy into the disk. A major unresolved issue is that there is no further support to complete the hardware and conduct the tests to finally verify or dismiss the anomalous force claims of Podkletnov. MSFC is pursuing other funding options and also asked if GRC would be able to receive the hardware and complete the tests. One further note, during a August 15 briefing by Millis to the NASA Chief Scientist, Dr. Shannon Lucid, Dr. Lucid stated that it would be disappointing if these provocative claims were never reliably resolved, and wished to be informed of the results.

July 17, 2002

On July 11-12, 2002, Marc Millis and Paul Raitano visited West Virginia's Institute for Scientific Research (ISR) Inc. (formerly named the Institute for *Software* Research), to check on the progress of the Congressionally earmarked tasks on Breakthrough Propulsion Physics. This also included a visit to the physics department of West Virginia University (WVU) to check on a subtask to the ISR work. The work has progressed to where experiments are underway to test for a Heaviside force, but the rectification of this oscillating force into a net thrust can no longer be attempted. The WVU work involves a replication of a 1980 experiment for torsional evidence of Heaviside forces. Both ISR and WVU requested an extension till the end of the calendar year to complete their experiments. Also, while there, Millis briefed ISR on the sensitivities and unresolved technical issues of the "Asymmetrical Capacitor Thruster" tests being conducted under the MSFC-managed earmark to ISR. Due to the longstanding, unresolved issues underlying this effect and its variants, it is crucial that these tests be as complete and impartial as possible.

June 28, 2002

The budget for the Breakthrough Propulsion Physics Project is being cut. Not only are all future years' budgets in question, but also $202K of the funds already allocated for this year have been requested to be withdrawn. It is uncertain if these reductions will be repaired. These cuts will prevent any future calls for proposals for BPP research and prevent the re-establishment of NASA Glenn Research

Center's (GRC) in-house BPP research. It was this in-house research, in the early 1990s, that gave rise to the NASA-wide BPP Project, and which was put on hold to establish the overall NASA Project. Due to the dwindling capability to keep current on emerging research and methods, steps are underway to re-establish the GRC in-house capability. This would restore the "smart buyer" capabilities, economically utilize NASA facilities and expertise, and give NASA the flexibility to pursue topics on a short-response basis.

With the funds still remaining, the BPP Project will continue the establishment of the BPP Consortium’s basic operations, including the establishment of the Advisory Council and Internet-accessible BPP Databases. Since the Consortium is operated by the non-profit Ohio Aerospace Institute (OAI), it is configured to receive non-NASA funds, such as from DOD, DOE, Industry sponsors, or philanthropists. The BPP Project will also be able to retain the Document Control service contractor to maintain Project reports, databases, and correspondence; developing and utilizing the "standard replies" for dealing with the large volume of BPP correspondence; and providing research assistance (journal articles, abstracts, papers, bibliographic information, etc.) to support BPP research requests.

June 7, 2002
With the addition of another full-time Civil Servant, the Breakthrough Propulsion Physics (BPP) Project can now address the in-house experimental research called for by the BPP Project Plan. Specifically, Paul Raitano transferred to the BPP Project and will be responsible for conducting in-house experiments, including setting up the BPP lab. Marc Millis, the founder and former Project Manger of BPP, is continuing his transition out of Project Management and is resuming his research into issues of reactive media for “space drives.”

May 24, 2002
At the "Propulsion for Space Transportation of the XXI Century" symposium, held May, 13-17, 2002, in Versailles, France, there were 7 presentations related to Breakthrough Propulsion Physics (BPP). This included 2 different presentations from Marc Millis (on BPP methods & status); presentations on the European Space Agency (ESA) study, "Gravity Control and Possible Influence on Space Propulsion," by Orfeu Bertolami and Martin Tajmar; presentations by Anders Hansson and Claudio Maccone on BPP research needs; and a presentation by Patrick Cornille on the controversial "Lifter" effect (a.k.a. Biefeld-Brown). Based on the results of the ESA study, and contrary to their prior expectations, ESA has decided to continue support of BPP research and is continuing collaborative discussions with Marc

Millis, of NASA, to avoid duplication of effort and to share results. They are also considering having an ESA representative on the BPP Consortium Advisory Council.

USA TODAY selected the NASA Breakthrough Propulsion Physics (BPP) web site; "Warp Drive, When?" (http://www.grc.nasa.gov/WWW/PAO/warp.htm), as a "Hot Site" in their May 15, 2002 edition of USATODAY.com. This BPP web site educates the general public about the challenges and emerging concepts for interstellar travel. This site has received numerous awards since its emergence in 1995.

An article appeared in the May 11, 2002 issue of Wired.com/news, by Michelle Delio, about the controversial, and as-yet unresolved, "Lifter" effect; also known as "Asymmetrical Capacitors," "Electrogravitics," and the "Biefeld-Brown effect (circa 1955)." This effect claims anomalous thrust from high-voltage capacitors, and therefore, falls within the scope of Breakthrough Propulsion Physics (BPP). Marc Millis was quoted in the article. The version cited in the Wired article is from Tim Ventura, a UNIX programmer for AT&T Wireless. This topic is controversial because most of the recent work, work that was not coordinated with the BPP Project, has focused on promoting claims rather than on credibly resolving the unknowns, and some have published these claims in inappropriate venues. Such activities have tainted the overall credibility of BPP research, by association. Fortunately, a new effort, involving a reprogrammed Congressional earmark, has been tasked to conduct an independent, experimental test of these "Asymmetrical Capacitor" claims. This new effort, managed by MSFC, involves a MSFC-managed earmark to the West Virginia Institute for Software Research (ISR). This work is now being coordinated with the BPP Project.
An overview of NASA's advanced propulsion research appeared in a May 22, 2002 article by Leonard David, in Space.com. The article covered the MSFC-managed "In-Space Transportation Investment Area" and the GRC-managed "Breakthrough Propulsion Physics (BPP) Project."

Week Ending 05/10/2002
Marc Millis visited the U.S. Air Force Academy (USAFA) on May 2-3, 2002, to view progress on a Breakthrough Propulsion Physics (BPP) task, to give presentations about the NASA BPP Project, and to discuss future Academy collaboration. A Cadet and a member of the faculty are conducting analytic and experimental tests of claims from the West Virginia Institute for Software Research (ISR). The ISR work, initiated via an FY00-01 Congressional earmark, explores old theories of electromagnetic momentum that might be usable for breakthrough

propulsion. Although not completed, Cadet analytical assessment indicates the ISR perspectives will not lead to breakthrough propulsion, but did identify an experimental test of related issues of the coupling of electromagnetism and space. The experiments explore the effects on the vacuum from specific combinations of electrostatic fields and oscillating currents. While there, Millis participated in the experiments along with Martin Tajmar (of Austria's Seibersdorf Research), a consultant on this project. Further instrumentation refinements are needed to eliminate cross-coupling. To inform the Academy about the NASA BPP Project, Millis was invited to give presentations to the faculty and four Cadet classes. Discussions between Millis and USAFA Faculty are continuing on the possibility of using such Cadet educational projects as venue for other low-cost, independent assessments of BPP claims.

Week Ending 03/01/2002

On Friday, February 22, 2002, Marc Millis and other Glenn participants of the Breakthrough Propulsion Physics (BPP) Project met with representatives of the West Virginia Institute for Software Research (ISR) and the U.S. Air Force Academy (USAFA) to discuss experiment options to complete the ISR Congressional earmarked research task. This task explores old theories of Heaviside and Slepian, regarding electromagnetic momentum and the possibility that such electromagnetic momentum might be useable for propulsion. ISR estimates completing their work by May, 2002. The USAFA estimates completing their independent test of the ISR effects by June, 2002.

Checking on the status of the University of Washington research task sponsored by the Breakthrough Propulsion Physics Project, Marc Millis visited Dr. John Cramer at the University on February 26, 2002. This task, an independent test of the transient inertia effect claimed by Jim Woodward, is nearing completion. Data has been taken for two of the three planned experiments. Even though the data is still being analyzed, preliminary assessments have not observed evidence of inertial changes. Completion is now expected by June.

Week Ending 01/18/2002

A significant step for the Breakthrough Propulsion Physics (BPP) Project has been taken with the establishment of a Breakthrough Propulsion Physics Research Consortium via a Cooperative Agreement with the Ohio Aerospace Institute. This research Consortium will reach out to geographically dispersed researchers to find, support, and coordinate the best research to make credible progress toward the visionary BPP goals, and to disseminate the results for the benefit of all. The Consortium will include an Advisory Council, will enable member participation, conduct surveys, solicitations, and prioritization of candidate research, and maintain an electronic database of research proposals and results. It is envisioned that the Advisory Council will include renowned representatives of the physics community, a liaison of NASA Glenn, and representatives from the Department of Defense, the Department of Energy, and any significant outside sponsors.

Week Ending 10/26/2001

Marc Millis gave an invited lecture about the NASA Breakthrough Propulsion Physics Project, on Sunday, October 21, at the Pennsylvania State University as part of their "Friedman Public Lecture Series." Penn State's Department of Astronomy and Astrophysics runs this series and this season's theme is "Black Holes and Time Machines." Millis was the kick-off lecturer and the closing lecture will be Lawrence Krauss, in April 2002. About 150 people attended, consisting of students, faculty and the general public. During the visit, Millis met with graduate students and faculty from the Astronomy and Astrophysics Department and the Physics Department. This was the 3rd invited lecture accepted by Millis in 2001; with the other two being the Berkeley National Lab, in June, and the California Institute of Technology, in February.

Week Ending 08/17/2001

Three Breakthrough Propulsion Physics sessions chaired by Marc Millis were held at the AIAA Joint Propulsion Conference. Eighteen papers in total were presented, including all six of the BPP-funded research activities (including one from NASA MSFC), two additional papers from NASA GRC, and international contributions from the United Kingdom, Austria, Russia, and Argentina. The sessions were very well attended (standing room only) and often sparked vigorous discussions. Separate discussions were held with representatives from the Air Force (AFRL/Edwards) and European Space Agency, regarding potential future collaboration with the BPP Project. The JPC sessions with papers from the NRA funded activities satisfied a GRC Strategic Implementation Plan milestone.

Week Ending 2/11/2000

At the 2000 Space Technology and Applications International Forum, Marc Millis co-chaired a conference including four sessions on Breakthrough Propulsion Physics (BPP). The quality and quantity of papers were definitely improved over last year (19 papers in proceedings), and feedback was quite positive. Also, one of the papers from last year's sessions won "Best Student" paper (T.H. Mahood). The BPP Project is successfully drawing out concepts and identifying the critical issues related to seeking propulsion breakthroughs. In support of this event, Mr. Millis was able to get the Air Force European Office of Aerospace R&D to pay for the travel of five of the European presenters, at no cost to NASA.

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Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004

ARCHIVE

- [1999, 01] BPP Project gets top score from Independent Review Panel
- [1998, 10] White Paper
- News Release: "Research Selections"
- Criteria for previous Call for Proposals http://www.grc.nasa.gov/www/bpp/NRA-99.htm
- [1998, Oct. 6-8] BPP Lecture Series, Ohio Aerospace Institute, Cleveland, Ohio
- [1998, 06] Description of project goals, methods, and emerging opportunities (NASA/TM-1998-208400)
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These items predate the official NASA project:

- [1994-1996] Grass-roots collaboration - Interstellar Propulsion Society
- [1994] "Practical Robotic Interstellar Flight: Are We Ready?", Conference, New York, NY
- [1990-1995] Lewis Research Center "Space Coupling Working Group"
- [1989-1993] Lewis Research Center "Vision-21" Group (NASA CP-10059, and NASA CP-10129)

Essays:

- [1997] Why Now?
- [1996/1997] Enabling Interstellar Missions - why interstellar travel is so difficult, and what is needed to overcome the challenges.

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Curator: -- not presently available --
Last update: May 13, 2004

NASA BREAKTHROUGH PROPULSION PHYSICS PROGRAM
- A White Paper -

Marc G. Millis, NASA, Lewis Research Center
1998, October, 2

There comes a time to seek the next revolutions in technology. That time is when the existing methods are approaching their theoretical limits and when clues are emerging for new methods that might surpass those limits1. Such is the case with rocket technology. Rockets are fundamentally limited by propellant. Propellant mass rises exponentially with increases in payload, destinations, or speed. This limit cannot be overcome with engineering refinements: it is based on the very physics of rocketry. To dramatically reduce the expense of near-Earth journeys or to journey beyond our Solar system in a reasonable time, new propulsion physics is required.

Theories and phenomena have emerged in recent scientific literature that provide new paths to seek such propulsion physics - breakthroughs that could revolutionize space flight and make human voyages to other star systems possible. It should be noted that some of these are too new to have been confirmed or dismissed, but their implications warrant investigation. Experiements2 and theories3 of quantum physics indicate the possible existence of vacuum fluctuation energy, including a force-producing effect (Casimir effect2). Theories using general relativity have examined methods and issues of circumventing the light-speed limit (wormholes4,5, warp drives6, an Krasnikov tubes7). Quantum tunneling experiments have revealed a phenomenon8 that some interpret as faster-than-light9. Gamma ray bursts have been observed in the cosmos that indicate an energy production mechanism beyond that explainable with current theories10. Other astronomical observations reveal an expansion rate for the universe that appears to be accelerating - contrary to our current understanding11,12. Anomalous weight reductions have been reported over spinning superconductors13,14. And all of these are in addition to already knowing that gravity, electromagnetism and spacetime are coupled phenomena15 - a coupling that is still not fully understood.

These are intriguing developments. Although many of these are already being explored by the scientific community to determine their validity and relevance to the age of the universe, the mystery of missing matter, or the coupling of the fundamental forces, there has not been an effort to apply these developments specifically to the goals of space flight. Some researchers consider it premature to seek propulsion applications before the underlying physics is fully developed, and some even consider propulsion breakthroughs unachievable. Progress, however, is not made by conceding defeat. To determine if science has evolved sufficiently to begin propulsion research and to begin such research, the NASA "Breakthrough Propulsion Physics" program was created in 1996. This program, managed by Lewis Research Center, is part of the Advanced Space Transportation Program managed by Marshall Space Flight Center.

To implement this program, the following strategy is being employed: First, the specific propulsion goals were identified and the methods to seek credible progress were articulated[16,17]- credible progress toward incredible possibilities. Second, conference sessions, workshops and internet sites were supported and will continue to be supported to foster collaboration and to identify affordable research. Next, beginning in fiscal 1999, an annual NASA Research Announcement will solicit and support research. This solicitation is open to academia, industry, government labs, and NASA centers. Selection will be via a peer review process using prioritization criteria that were specifically designed for this program. Because it is too early to focus on a given approach, multiple, different approaches will be supported from the top ranking candidates. Tasks are requested to be short duration (1-3 years) and low cost ($50K-150K). After two years of supported research, another workshop will be conducted to determine if the progress gained is worth sustaining the program. If progress is promising, increased funding will be sought. If not, then the program will be put on hold until further significant scientific developments emerge. At this time, a modest budget has been obtained for the research solicitation.

To focus research, the following three goals were identified as breakthroughs that would revolutionize space flight. Achievement of any one of these would usher in a new era, where people could explore deeper into space, reaching more destinations, in less time and with less infrastructure. Achievement of all three would enable human voyages to other star systems.

(1) MASS: Discover new propulsion methods that eliminate or dramatically reduce the need for propellant. This implies discovering fundamentally new ways to create motion, presumably by interactions between matter, fields, and spacetime, including the possibility of manipulating gravity or inertia.

(2) SPEED: Discover how to attain the ultimate transit speed to dramatically reduce travel times. This implies discovering a means to move a vehicle at or near the actual maximum speed limit for motion through space or by the motion of spacetime itself (if possible, this means circumventing the light-speed limit).

(3) ENERGY: Discover fundamentally new modes of onboard energy generation to power these propulsion devices. This third goal is included since the first two breakthroughs could require breakthroughs in energy generation, and since the physics underlying the propulsion goals is closely linked to energy physics.

Since these goals are presumably far from fruition while support is sought in the near-term, the objective of this program is to produce near-term, measurable, and credible progress toward conquering these three goals. It is essential that the long-range goals be broken down into smaller steps; research that addresses the immediate issues of comparing the emerging physics to the program goals. The Scientific Method has been adapted to measure progress, similarly to how the Technology Readiness Levels are used to gauge engineering progress. Also, success is defined as learning more about reaching the breakthrough, rather than actually achieving the breakthroughs. Negative results are still progress.

The emphasis on credibility is because such long-range ambitions are often tainted by non-credible work or even "pathological science"[18,19], and since genuine progress can only be made with credible work. Conversely, to reach for breakthroughs requires vision. Balancing vision with credibility is challenging since genuinely new, credible ideas will extend beyond the established knowledge base and can sometimes appear to contradict this base. Criteria have been built into the proposal ranking system to address this challenge. Related to this, skepticism is actively sought. By identifying the objections, one identifies research objectives. Another feature to enhance credibility is that this program does not promise to deliver breakthroughs, but does promise to deliver progress toward achieving the breakthroughs. This position is taken since it is too soon to know if the desired breakthroughs are indeed achievable.

Another emphasis of this program is empiricism. This emphasis is used to help balance credibility with vision and to aim science toward becoming technology. When seeking new ideas, it is crucial that the ideas are consistent with credible data, but they may entertain new interpretations of the data. Theories are interpretations to explain observations of nature, while the empirical data is nature. Theories also evolve overtime as we gain more understanding, but the data do not change. For example, the data of the motions of the planets are the same, regardless if one uses the Copernicus theory or the Earth-centered theory to describe the data. Empiricism is also useful to focus science toward technology. Experiments, being hardware, are closer than theory to becoming technology.

Since the needed expertise and skills are not resident in any single center or agency, this program relies on collaborative networking. This networking is open to all the NASA centers, government labs, universities, industries, and credible individuals. Recently, international collaboration was also invited17. To enable this networking, workshops, conference sessions, and the internet are used. To date, about 200 researchers have expressed interest in assisting. The internet sites are still being constructed (http://www.lerc.nasa.gov/WWW/bpp/).

Regarding possible research, about 80 tasks were identified during an August 1997 workshop. Quantum tunneling experiments were suggested using matter rather than photons and it was suggested to devise experiments to search for nonlinear quantum effects to address questions of faster-than-light transport. To address the energy and causality problems of warp drives and wormholes, quantum gravity theory was suggested. To address the issues and unknowns of vacuum energy, experiments were suggested to determine if the vacuum energy exists as predicted, and to test theories linking vacuum fluctuations to inertia and gravity20-23. In addition, experiments were suggested to test other perspectives of the coupling between gravity and electromagnetism24-26, including the observation of anomalous weight reductions over spinning superconductors13,14.

Closing Remarks

NASA has defined the goals and a strategy to begin making progress toward breakthrough propulsion. In addition to the benefits to NASA, this program also promotes general scientific advancements. In the first step of the scientific method, where one clearly formulates the problem to guide the search for knowledge, this NASA program has a unique problem: space flight. Such a focus will present different lines of inquiry than general physics alone. By asking different questions and looking along a different path, this program provides an opportunity for physicists to search for discoveries that may otherwise be overlooked or delayed. With the participation of the NASA centers, other government labs, academia, and industry, this progress can now begin.

Summary of Key Points

- Just beginning: finding out if work can be done and if this work will result in meaningful progress.
- Focused on the critical propulsion challenges - breakthroughs to achieve interstellar travel.
- Balancing credibility with vision.
- Seeking low cost, incremental, and measurable progress.
- Research solicitation to begin in fiscal 1999, open to all categories of organizations.

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Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004

Millis, M. "Challenge to Create the Space Drive," In Journal of Propulsion and Power (AIAA), Vol. 13, No. 5, pp. 577-682, (Sept.-Oct. 1997).

web version 08/20/99
Note: Figures did not transcribe correctly from original report.

The Challenge To Create The Space Drive

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ABSTRACT

To travel to our neighboring stars as practically as envisioned by science fiction, breakthroughs in science are required. One of these breakthroughs is to discover a self-contained means of propulsion that requires no propellant. To chart a path toward such a discovery, seven hypothetical space drives are presented to illustrate the specific unsolved challenges and associated research objectives toward this ambition. One research objective is to discover a means to asymmetrically interact with the electromagnetic fluctuations of the vacuum. Another is to develop a physics that describes inertia, gravity, or the properties of spacetime as a function of electromagnetics that leads to using electromagnetic technology for inducing propulsive forces. Another is to determine if negative mass exists or if its properties can be synthesized. An alternative approach that covers the possibility that negative mass might not exist is to develop a formalism of Mach's Principle or reformulate ether concepts to lay a foundation for addressing reaction forces and conservation of momentum with space drives.

INTRODUCTION

New theories have emerged suggesting that gravitational and inertial forces are caused by interactions with the electromagnetic fluctuations of the vacuum. [1,2] There have also been studies suggesting experimental tests for mass-altering affects [3], and a theory suggesting a "warp drive." [4] With the emergence of such new possibilities, it may be time to revisit the notion of creating the visionary "space drive." Space drive, as defined here, is an idealized form of propulsion where the fundamental properties of matter and spacetime are used to create propulsive forces anywhere in space without having to carry and expel a reaction mass. Such an achievement would revolutionize space travel as it would circumvent the present constraint of requiring propellant. Without such a discovery, human interstellar exploration may not be possible. [5]

One of the missing prerequisites to achieving this breakthrough is having a starting point for the research; a description of the specific problems to be solved. Without this first step of the Scientific Method there is no framework against which to assess, augment, and apply emerging science to the goal of creating a space drive. To provide such a starting point, a variety of hypothetical space drives are presented and analyzed to identify the specific problems that have to be solved to make such schemes plausible.

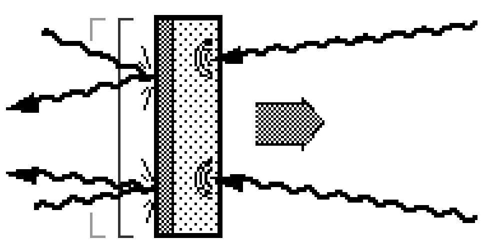
PROBLEM FORMULATION METHOD

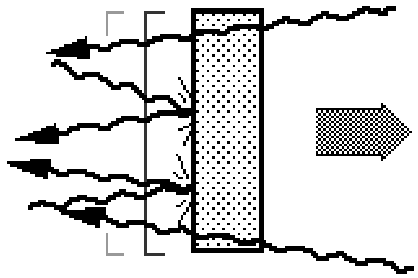
A NASA precedent for systematically seeking revolutionary capabilities is the "Horizon Mission Methodology." [6] This method forces paradigm shifts beyond extrapolations of existing technologies by using *impossible* hypothetical mission goals to solicit new solutions. By setting impossible goals, the common practice of limiting visions to extrapolations of existing solutions is prevented. This method forces one to look beyond existing methods and specify the technologies and sciences that are genuinely needed to solve the problem, whether the solutions exist yet or not.

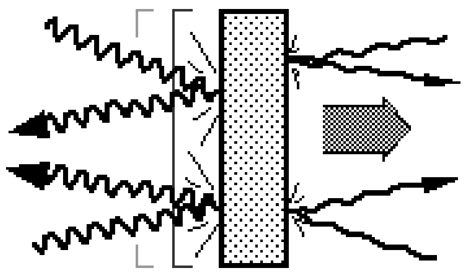
The theme of the Horizon Mission Methodology is followed here. The "impossible" goal targeted in this exercise is to create a space drive. In the spirit of the Horizon Methodology, the envisioned propulsion methods can entertain the possibility of physics yet to be discovered. However, to ensure that the envisioned methods are consistent with firmly established physics, the analysis imposes the constraints of conservation of momentum and energy, and requires that observed natural phenomena are not contradicted. From imposing these constraints, the characteristics needed to make space drives plausible can be identified.

Seven different hypothetical propulsion concepts were created for this exercise. These concepts were envisioned by considering analogies to collision forces and interactions with fields to produce net forces.

HYPOTHETICAL COLLISION SAILS







One means to produce force is collisions. Conventional rocket propulsion is fundamentally based on the collisions between the propellant and the rocket. These collisions thrust the rocket in one direction and the propellant in the other.

To entertain the analogy of collision forces for a space drive, consider the supposition that space contains a background of some form of isotropic medium that is constantly impinging on all sides of a vehicle. This medium could be a collection of randomly moving particles or electromagnetic waves, either of which possess momentum. If the collisions on the front of a vehicle could be lessened and/or the collisions on the back enhanced, a net propulsive force would result. Three variations of such a hypothetical collision-sail are illustrated in Fig. 1 through 3. In all these illustrations, the rectangle represents a cross sectional element of the sail and the wavy lines represent impinging waves of the isotropic radiative medium. The large arrow indicates the direction of acceleration.

For any of these concepts to work, there must be a real background medium in space. This medium must have a sufficiently large energy or mass density, must exist equally and isotropically across all space, and there must be a controllable means to alter the collisions with this medium to propel the vehicle. A high energy or mass density is required to provide sufficient radiation pressure or reaction momentum within a reasonable sail area. The requirement that the medium exist equally and isotropically across all space is to ensure that the propulsion device will work anywhere and in any direction in space. The requirement that there must be a controllable means to alter the collisions ensures that a controllable propulsive effect can be created.

The supposition that space contains an isotropic medium is reasonable. Space contains electromagnetic fluctuations of the vacuum, also called the Zero Point Fluctuations (ZPF) [7], Cosmic Background Radiation (CBR) [8], free hydrogen (protons) [9], the theoretically suggested virtual pairs [10] and possibly even dark matter.[11] Whether any of these media have all the characteristics needed to be used as a propulsive medium remains a subject for future research.

Regarding conservation of momentum, this condition can be satisfied by using the medium as the reaction mass. Any net momentum imparted to the vehicle must be equal and opposite to the momentum change imparted to the medium.

Regarding conservation of energy, this condition can be satisfied by imposing the constraint that whatever propulsive method or phenomenon is used, the total system energy before and after the propulsive effect is equal. This includes the energy state of the surrounding medium, the energy state of any energy sources on the vehicle, the kinetic energy imparted to the vehicle, and any loss mechanisms.

HYPOTHETICAL FIELD DRIVES

In addition to producing forces with collisions, forces can be produced from interactions between matter and fields. Gravitational fields accelerate masses and electric fields accelerate charges. To entertain the analogy of using field interactions to create a space drive, it is necessary to assume that there is some way for a vehicle to induce a field around itself that will in turn accelerate itself. Field drive concepts are more complex and more speculative than collision sail drives. A description of the critical issues follows.

Even if there was a device on a vehicle that could induce a force-producing field, there is still the question of whether such a field would accelerate the vehicle. A typical expectation is that the induced forces would just act between the vehicle’s field-inducing device and the rest of the vehicle, like blowing in your own sails, or trying to move a car by pushing on it from the inside. In such cases all the forces act internally and there would be no net motion of the vehicle. For reference, this issue can be called the "net external force requirement."

The net external force requirement is closely related to conservation of momentum. Conservation of momentum requires that the momentum imparted to the vehicle must be equal and opposite to the momentum imparted to a reaction mass. In the case of a field drive, there is no *obvious* reaction mass for the vehicle to push against.

Similarly to conservation of momentum is the issue of conservation of energy. This issue can be satisfied by imposing the constraint that whatever propulsive method or phenomenon is used, the energy required to create the effect is equal to the kinetic energy imparted to the vehicle and to whatever constitutes its reaction mass, plus any inefficiency losses. In addition, there is also the issue of controllability, insuring that the force-producing effect can be turned on and off at will.

A closely related aspect to controllability is sustainability. Sustainability refers to the ability to continue the propulsive effect throughout the vehicle’s motion. This implies that the force inducing effect must work in both an inertial frame and an accelerated frame. It also requires that the force-producing field is carried along with or propagated with the vehicle, or at least can be induced again after the vehicle has been set in motion.

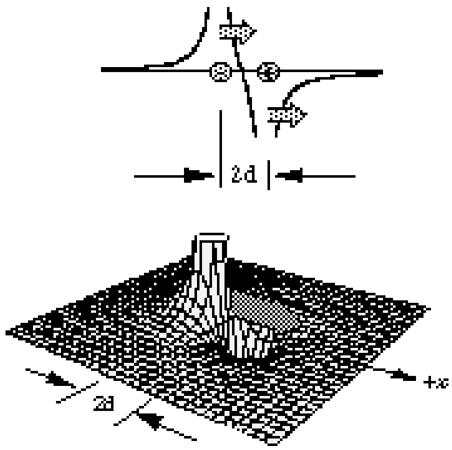
In the spirit of the "Horizon Methodology", it is assumed a priori that space drives are possible. By doing so and then by addressing the critical issues, the required physical characteristics of matter and space to make such propulsion methods plausible can be identified. Future research can then determine whether these conditions can be created with the phenomena that are known to exist, or at least indicate what other phenomena to search for.

Four hypothetical field drives, "Diametric Drive," "Pitch Drive," "Bias Drive," and "Disjunction Drive," are presented next and illustrated in Fig. 4 through 7. These concepts were envisioned by examining the characteristics that describe a field or how matter reacts to a field, and then assuming it is possible to modify a given characteristic of this relation. The Diametric Drive works with field sources, the Pitch Drive with the field itself, the Bias Drive with the properties of the space that contain the field, and the Disjunction Drive with the properties of matter that create and react to a field.

A common theme to all of these is that an *asymmetric* field is induced such that a gradient is located at the center of the vehicle, or more specifically at the center of whatever part of the vehicle will experience a reaction force from the field. An asymmetric field is required so that a net force is created on the vehicle.

These concepts are presented in the context of using mass and gravitational properties. A more thorough treatise would also have to address using space media and electromagnetic phenomena.

Diametric Drive



This first type of hypothetical field propulsion, as illustrated in Fig. 4, considers the possibility of creating a local gradient by the juxtaposition of diametrically opposed field sources across the vehicle. This is directly analogous to the "negative mass" propulsion suggested by Bondi [12], Winterberg [13] and Forward. [14] The diametric drive can also be considered analogous to creating a pressure source and sink in a space medium as suggested previously with the Induction Sail.

Negative mass propulsion is not a new concept. It has already been shown that is theoretically possible to create a continuously propulsive effect by the juxtaposition of negative and positive mass [12] and that such a scheme does not violate conservation of momentum or energy. [14] A crucial assumption to the success of this concept is that negative mass has negative *inertia*.

Qualitatively, this concept can be illustrated by the following equation:

$$V = (-m)\left(\frac{-G}{\sqrt{(x+d)^2+y^2}}\right) + (+m)\left(\frac{-G}{\sqrt{(x-d)^2+y^2}}\right) \quad (1)$$

where V is the gravitational scalar potential for the combined system, shown as a surface plot over an *x-y* plane in figure 4 (singularities have been truncated for clarity). The first term is the gravitational potential for the negative mass, -m, the second for the positive mass, +m. In both cases, G is Newton’s gravitational constant. The negative mass is located a distance, d, along the *x* axis behind the origin and the positive mass is located a distance, d, in front of the origin. The origin is taken to be the midpoint between the two masses along the *x* axis.

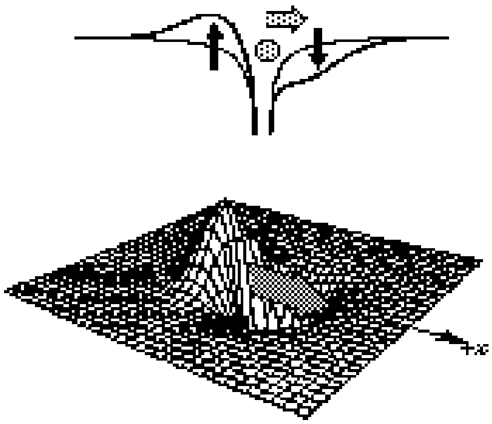
By taking the gradient of the scalar potential caused by the negative mass at the location of the positive mass, and of the positive mass at the location of the negative mass, the accelerations for each mass can be calculated;

$$a_{-m} = \frac{-G(-m)}{(2d)^2} \quad (2a)$$

for the negative mass which is in the positive *x* direction, and

(2b)

for the positive mass which is also in the positive *x* direction. Their combined interactions result in a sustained acceleration of both masses in the same direction. This result is also obtained by Forward using an alternative analysis. [14]



Pitch Drive

This second type of hypothetical field mechanism, as illustrated in Fig. 5, entertains the possibility that somehow a localized slope in scalar potential is induced across the vehicle which causes forces on the vehicle. In contrast to the diametric drive presented earlier, it is assumed that such a slope can be created without the presence of a pair of point sources. It is not yet known if and how such an effect can be created.

Qualitatively, this can be illustrated by the following equation:

$$V = \left[\frac{-Gm}{r}\right] + \left[-Axe^{-r^2}\right] \quad (3)$$

where V is the gravitational scalar potential for the combined system, shown as a surface plot over an *x*-*y* plane in figure 5, which is equal to the superposition of the potentials from the vehicle and the induced pitch effect. The term for the vehicle's gravitational potential is the familiar Newton's gravitational potential where r is the distance from the source mass (r2 = *x*2 + *y*2 for the *x* - *y* plane). The origin is taken to be at the center of the vehicle. To entertain the possibility of a Pitch Drive, a localized gradient in the scalar gravitational potential is superimposed across the symmetric gravitational potential already present from the vehicle's mass. This induced pitch effect is represented by a magnitude, A (units of acceleration), with a negative slope in the positive *x* direction, and is localized by a Gaussian distribution, e-r2, over the distance, r, centered at the origin. This localizing equation was arbitrarily chosen for illustration purposes only.

By taking the gradient of the scalar potential at the location of the vehicle, specifically the derivative of V with respect to r of the induced pitch effect at r=0, the acceleration for the vehicle is determined to be equal to A, and acts in the positive *x* direction.

Bias Drive

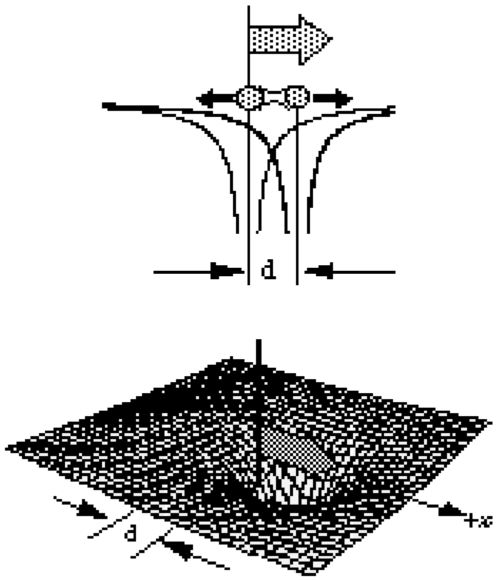
The third type of hypothetical field mechanism, as illustrated in Fig. 6, entertains the possibility that the vehicle alters the properties of space itself, such as the gravitational constant, G, to create a local propulsive gradient. By modifying Newton's constant to have a localized asymmetric bias, a local gradient similar to the Pitch Drive mechanism results.

Qualitatively, this concept can be illustrated by the following equation:

$$V = \left(Bxe^{-r^2}+1\right)\left(-G\frac{m}{r}\right) \quad (4)$$

where V is the gravitational scalar potential plotted over an *x*-*y* plane, shown as a surface plot in Figure 6. This scalar potential is described by the familiar Newton's gravitational potential on the right which is multiplied by a spatially asymmetric modifier on the left. The spatially asymmetric modifier is represented by a magnitude, *B* (units of inverse distance), multiplied by *x*, to give a positive slope in the positive *x* direction, and is localized by a Gaussian distribution as with the Pitch Drive. The "+1" identity term is necessary to return the Newtonian gravitational potential to its original form at large distances (r>>0). Unfortunately, it is not possible to present a qualitative representation for the resulting acceleration for this hypothetical example since the gradient of this scalar potential produces a singularity at the origin.

A similar concept by Alcubierre [4] suggests creating a propulsive effect by asymmetrically altering spacetime itself. Alcubierre theorized that by expanding spacetime behind the vehicle and contracting spacetime in front of the vehicle, faster-than-light travel would be possible without violating general relativity. The net effect is that this "warped" space and the region within it would propel itself "with an arbitrarily large speed." Observers outside this "warp" would see it move faster than the speed of light. Observers inside this "warp" would feel no acceleration as they move at warp speed. Although a sub-light-speed space drive would constitute a sufficiently important breakthrough, the possibility that a space drive may also enable faster-than-light transport is intriguing. The feasibility of this "warp drive" theory is an open issue.



Disjunction Drive

The fourth type of hypothetical field drive, as illustrated in Fig. 7, entertains the possibility that the source of a field and that which reacts to a field can be separated. By displacing them in space, the reactant is shifted to a point where the field has a slope, thus producing reaction forces between the source and the reactant. It is assumed that the source and reactant are held apart by some sort of rigid device.

Obviously, a critical issue of this scheme is whether the field’s source is a separate entity from that which reacts to a field. This perspective is similar to that used in the analysis of the properties of negative mass. [12] In the course of examining the nature of hypothesized negative mass, three different masses can be distinguished: the "source mass," "reactant mass," and "inertial mass." Although these distinctions were made to classically analyze the behavior of negative mass, they do invite speculation. Could either a "source" or "reactant" mass be mimicked through some coupling between gravity, electromagnetism and spacetime? If so, the propulsive effect suggested above may be possible. This is unknown at this time.

Qualitatively, this concept can be illustrated by the following equations:

$$V = \frac{-G m_S}{\sqrt{(x-d)^2 + y^2}} \quad (5)$$

where V is the gravitational scalar potential plotted over an *x-y* plane as a surface plot in figure 7 which is equal to the familiar Newton's gravitational potential of the *source* mass, m_S, which is a distance, d, along the *x* axis, from the reactant mass. The source mass is defined to have the property that it only causes a field, but does not react to one. The reactant mass is defined to react to the presence of a field, but not to cause one. Thus, there is no force on the source mass from the reactant mass.

To illustrate how this concept works, examine the sum of the resulting forces:

$$\Sigma \text{ forces} = \frac{G m_S m_R}{d^2} + m_S a + m_R a \quad (6)$$

The first term of the sum is the gravitational force from the source mass, m_S, acting on the reactant mass, m_R. By definition, there is no force created on the source mass from the reactant mass, and hence, no term for that force in this equation. However, to entertain the possibility that the source and the reactant mass have inertial mass, terms are included for the reaction forces due to these inertiae. These reaction forces are the second and third terms in the summation, where m_{Si} is the inertia of the source mass and m_{Ri} is the inertia of the reactant mass. Since it is assumed that the masses are rigidly connected by whatever device has pulled them apart, the acceleration, a, is the same for both masses. Solving for the acceleration gives:

$$a = \left(\frac{G}{d^2}\right)\left(\frac{m_S m_R}{m_{Si} + m_{Ri}}\right) \quad (7)$$

which acts in the positive *x* direction.

Although existing evidence strongly suggests that the source, reactant, and inertial mass properties are inseparable, any future evidence to the contrary would have revolutionary implication to this propulsion application.

REMAINING RESEARCH

There are a variety of unexplored paths toward discovering the physics for a space drive. To explore the collision sail concepts it would be useful to seek any means to interact asymmetrically with the media that are known to exist in space. In particular, the medium of the electromagnetic fluctuations of the vacuum, also called the ZPF, is a promising candidate because of its high energy density, estimated to be as high as 10^{114} Joules per cubic meter. [3] A recent experiment to reexamine the Casimir force, which is an empirical artifact of this energy density, found agreement with the theory at the level of 5%. [15]

Multiple research paths exist to further explore field drive concepts. First, the concept of negative mass, with its inherent negative inertia, could be further explored. Another research path that covers the possibility that negative mass cannot exist, is to develop a formalism of Mach's Principle or reformulate ether concepts to provide an alternative means to satisfy momentum conservation for field drives. Such formulations would also have to address how to impart reaction forces against space itself. A more general approach that may even encompass these other two approaches is to develop a physics that describes inertia, gravity, or the properties of spacetime as a function of electromagnetics that leads to using electromagnetic technology for inducing propulsive forces.

Regarding the physics of negative mass, it is not know whether negative mass exists or if it is even theoretically allowed, but methods have been suggested to search for evidence of negative mass in the context of searching for astronomical evidence of wormholes. [16] If negative mass is found to exist and if methods can be eventually engineered to collect and handle negative mass, it seems reasonable that a propulsive effect could be engineered as previously discussed with the Diametric Drive. If negative mass does not exist naturally, it is still possible, in the spirit of the Horizon Methodology, to consider the alternative of artificially synthesizing negative mass effects using some as-yet-undiscovered physics, perhaps using a form of gravity-electromagnetic coupling.

The idea of discovering some gravity-electromagnetic coupling goes beyond the idea of mimicking negative mass. If there is any way to modify gravity, inertia, or the properties of spacetime using electromagnetics, it may be possible to mimic negative mass to create a gravitational dipole, induce gravitational or electromagnetic fields to create a Pitch Drive, or modify other properties of space to create a Bias Drive.

The idea of using one phenomenon to control another is not new. Electric fields are used to create magnetic fields. By knowing the specifics of how these phenomena are coupled, it is possible to engineer such effects. In the case of a space drive it is desired to create an acceleration-inducing field using some phenomenon like electromagnetics that can be readily controlled.

Electromagnetism is suggested as the control phenomenon for two reasons: electromagnetism is a phenomenon for which we are technologically proficient, and it is known that gravity, spacetime, and electromagnetism are coupled phenomena. In the formalism of general relativity this coupling is described in terms of how mass warps the spacetime against which electromagnetism is measured. In simple terms this has the consequence that gravity appears to bend light, red-shift light, and slow time. These observations and the general relativistic formalism that describes them are experimentally supported. [9] Although gravity's effects on electromagnetism and spacetime have been observed, the reverse possibility, of using electromagnetism to affect gravity, inertia, or spacetime is unknown. To explore this possibility, it would be advantageous to have a formulation that describes these observed couplings as a function of electromagnetics.

Electromagnetism is also suggested as a target phenomenon for space drive research because of the ZPF. The ZPF is an electromagnetic phenomenon. Discovering any way to react asymmetrically with the ZPF would likely create a space drive. ZPF has also been theorized to be an underlying phenomenon to inertia and gravity [1,2], and experiments have been suggested to test these theories and to test other related speculations on the relation between the ZPF and mass properties. [3] It should be noted that these theories were not written in the context of propulsion and do not provide *direct* clues for how to electromagnetically manipulate inertia or gravity. Also, these theories are still too new to have either been confirmed or discounted. Despite such uncertainties these theories provide new, alternative approaches to search for breakthrough propulsion physics.

Inherent to all the propulsive mechanisms discussed above is the need to generate an asymmetric field, one that results in a *net* acceleration of the vehicle. One way to search for such asymmetric effects is to search for nonlinear or non-conserved effects. If, for example, there exists some characteristic coupling between electromagnetism, spacetime, inertia, or gravity that behaves nonlinearly, has some hysteresis, or is non-conserved (analogous to friction) it may be possible to create net forces from imbalanced, cyclic perturbations of this effect.

To illustrate this possibility, consider the analogy of an irregularly oscillating mass affixed to a cart that is initially at rest on the floor. When the mass moves slowly in one direction its reaction forces are not sufficient to overcome the static coefficient of friction between the cart and the floor and the cart remains still. When the mass moves quickly in the other direction its reaction forces are sufficient to overcome the static coefficient of friction, and the cart rolls. Repeating this cycle results in a net motion of the cart. If there are any field properties of space that have such a characteristic non-conserved interaction analogous to friction, then it may be possible to create an analogous propulsive effect in space.

A more conventional example which better illustrates the possibilities of nonlinear propulsion, is a method suggested by Landis. [17] This concept outlines a technique for changing the orbits of satellites without using propellant, and does so using conventional physics. It uses tethers on a satellite to take advantage of the nonlinear nature of a gravitational well. If the orbiting satellite extends a tether toward Earth and another tether away from earth, the imbalanced reactions will create a net force toward the Earth. This is because the downward force on the near-Earth tether increases more than the outward force on the outer tether as the tethers are deployed. By alternately deploying and retracting long tethers at different points during the orbit (apogee and perigee), an orbiting satellite can change its orbital altitude or eccentricity.

Another approach is to revisit the field properties of space itself in search of evidence of imbalanced forces. One experiment to explore this possibility is where a homopolar motor is used to illustrate a paradox of apparently imbalanced magnetic reaction forces. [18] Another is from experimental observations of unipolar induction that explores the relation between magnetic fields and the surrounding space. [19]

To further explore the propulsive implications of any of these imbalanced force concepts, it is necessary to fully address the law of conservation of momentum. In the case of the tether example discussed above, the Earth acts as the reaction mass to conserve momentum. In the case of negative mass propulsion, conservation of momentum is satisfied by taking advantage of the negative inertia of negative mass. [14] With the remaining field drives, however, research will be required to determine how the surrounding space can be used to satisfy conservation of momentum.

One approach to conserve momentum is to consider space itself as the reaction mass. This approach evokes the old idea of an "ether." To be strictly consistent with empirical evidence, such as the Michelson-Morely experiment, any further research to revisit the idea of an ether would have to impose the condition that an ether is electromagnetically Lorentz invariant. Note that this condition is a characteristic of the ZPF. [7]

An alternative to considering space as the reaction mass is to further develop Mach’s Principle. Mach’s Principle asserts that surrounding matter gives rise to inertial frames, and that the inertial frames are somehow connected to the surrounding matter. [9] Mach wrote that although he felt a connection to the surrounding matter was required for the property of inertia to be detectable, he also admitted that such a treatment was not necessary to satisfactorily describe the laws of motion. [20] To search for new, additional laws of motion to explore the goal of field drives, however, if may be useful to revisit Mach’s Principle more literally. Specifically, to be useful for propulsion physics, a formalism of Mach’s Principle is required that provides a means to transmit reaction forces to surrounding matter. This implies developing a quantitative description for how the surrounding matter creates an inertial frame, and how pushing against that frame with a space drive is actually pushing against the distant surrounding matter.

It is also possible to consider the very structure of spacetime itself as a candidate for propulsive interactions. If it were possible, for example, to create asymmetries in the very properties of spacetime which give rise to inertial frames, it may be possible to create net inertial forces. This is similar to the "warp drive" suggested by Alcubierre. [4]

It is also conceivable that other research approaches exist. To further explore any of these possibilities, it would be useful to have a succinct problem statement to guide the evaluation and application of emerging science to the goal of creating a space drive. Such a problem statement is offered next.

PROBLEM STATEMENT

The critical issues for both the sail and field drives have been compiled into the problem statement offered below. Simply put, a space drive requires some controllable and sustainable means to create asymmetric forces on the vehicle without expelling a reaction mass, and some means to satisfy conservation laws in the process. Regardless of which concept is explored, the following criteria must be satisfied.

(1) A mechanism must exist to interact with a property of space, matter, or energy which satisfies these conditions:

(a) must be able to induce an unidirectional acceleration of the vehicle.

(b) must be controllable.

(c) must be sustainable as the vehicle moves.

(d) must be effective enough to propel the vehicle.

(e) must satisfy conservation of momentum.

(f) must satisfy conservation of energy.

(2.1) If properties of *matter* or *energy* are used for the propulsive effect, this matter or energy...

(a) must have properties that enable conservation of momentum in the propulsive process.

(b) must exist in a form that can be controllably collected, carried, and positioned on the vehicle, or be controllably created on the vehicle.

(c) must exist in sufficiently high quantities to create a sufficient propulsive effect.

(2.2) If properties of *space* are used for the propulsive effect, these properties...

(a) must provide an equivalent reaction mass to conserve momentum.

(b) must be tangible; must be able to be detected and interacted with.

(c) must exist across all space and in all directions.

(d) must have a sufficiently high equivalent mass density within the span of the vehicle to be used as a propulsive reaction mass.

(e) must have characteristics that enable the propulsive effect to be sustained once the vehicle is in motion.

(3) The physics proposed for the propulsive mechanism and for the properties of space, matter, or energy used for the propulsive effect must be completely consistent with empirical observations.

CONCLUSIONS

Prior to the emergence of new theories suggesting connections between gravity, inertia, and the electromagnetic fluctuations of the vacuum, and the recent "warp drive" theory, the prospects for creating a space drive have seemed too far in the future to provide near term research opportunities. Now with these emerging theories, new research approaches exist. To provide a framework for taking advantage of these emerging theories and progressing science toward the goal of a space drive, a problem statement was needed and is now offered in this paper. Regarding the prospects for breakthroughs, consider the following quotes from past experts. These quotes were copied from Anderson’s article on the Horizon Methodology. [6]

"Heavier than air flying machines are impossible," "Radio has no future," "X-rays are a hoax."

- William Thomson (Lord Kelvin)
President of London’s Royal Society (1895-1904).

"There is no likelihood man can ever tap the power of the atom."

- Robert Millikan,
Nobel Prize in Physics (1923).

"The secrets of flight will not be mastered within our lifetime.. not within a thousand years."

- Wilbur Wright (1901).

ACKNOWLEDGMENTS

The following individuals contributed thought-provoking questions and critical reviews that were instrumental in completing this work: Michael Binder, Michael LaPointe, Ira T. Myers, Bryan Palaszewski, and Edward Zampino.

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Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004

Millis, M. G., **Breakthrough Propulsion Physics Workshop Preliminary Results**, NASA TM-97-206241, Nov. 1997
Presented at Plenary Session III Views of Future STAIF, Jan. 27, 1998, Albuquerque NM
Also Available in CP420, Space Technology and Applications International Forum-1998, ed El-Genk,
DOE CONF-980103, 1998, The American Institute of Physics 1-56396-747-2/98, pp 3-12.

web version 08/20/99

Note: Figures did not transcribe correctly from original report.

Note: The full workshop proceedings has been published and copies are available through the National Technical Information Service.

REF: Millis and Williamson, ed., "**NASA Breakthrough Propulsion Physics Workshop Proceedings**," NASA/CP-1999-208694**,** Proceedings of a conference held at and sponsored by NASA Lewis Research Center in Cleveland Ohio, August 12-14, 1997. (Jan. 99) (456 pg.)

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BREAKTHROUGH PROPULSION PHYSICS WORKSHOP PRELIMINARY RESULTS

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Abstract

In August, 1997, a NASA workshop was held to assess the prospects emerging from physics that might lead to creating the ultimate breakthroughs in space transportation: propulsion that requires no propellant mass, attaining the maximum transit speeds physically possible, and breakthrough methods of energy production to power such devices. Because these propulsion goals are presumably far from fruition, a special emphasis was to identify affordable, near-term, and credible research that could make measurable progress toward these propulsion goals. Experiments and theories were discussed regarding the coupling of gravity and electromagnetism, vacuum fluctuation energy, warp drives and wormholes, and superluminal quantum tunneling. Preliminary results of this workshop are presented, along with the status of the Breakthrough Propulsion Physics program that conducted this workshop.

INTRODUCTION

The objective of the NASA Breakthrough Propulsion Physics Program is to make measurable and credible progress toward the seemingly long range goal of creating propulsion breakthroughs. One of the first major milestones of the program was to convene a workshop with established physicists, government researchers and select innovators to jointly examine new theories and phenomena from scientific literature that have reawakened consideration that such breakthroughs may be achievable. Preliminary results of the workshop are presented along with the status of the program. This program, managed by Glenn Research Center, is funded out of the Advanced Space Transportation Plan (ASTP) managed by Marshall Space Flight Center (MSFC).

WORKSHOP GOALS

The purpose of the workshop was to examine emerging physics in the context of seeking *propulsion* breakthroughs. It is desired to channel the continuing advancements in science toward answering the fundamental questions of how to propel a spacecraft farther, faster, and more efficiently. Specifically, these goals are:

(1) MASS: Discover new propulsion methods that eliminate or dramatically reduce the need for propellant. This implies discovering fundamentally new ways to create motion, presumably by manipulating inertia, gravity, or by any other interactions between matter, fields, and spacetime.

(2) SPEED: Discover how to attain the ultimate achievable transit speeds to dramatically reduce travel times. This implies discovering a means to move a vehicle at or near the actual maximum speed limit for motion through space or through the motion of spacetime itself.

(3) ENERGY: Discover fundamentally new modes of onboard energy generation to power these propulsion devices. This third goal is included since the first two breakthroughs could require breakthroughs in energy generation, and since the physics underlying the propulsion goals is closely linked to energy physics.

To make near-term and measurable progress toward these ambitions, the workshop sought to produce a list of next-step, incremental research approaches. Specifically, this means identifying research tasks that are of relatively short duration and that address the immediate questions raised by the emerging physics and program goals.

WORKSHOP METHODS

Three major elements were used at the workshop; a plenary sequence of invited presentations to review emerging physics, a poster paper segment to provide thought-provoking ideas, and breakout sessions to produce a list of candidate next-step research tasks. The first day of the workshop and the morning of the second day featured the invited presentations. This included having opening remarks from Congressman Dennis Kucinich. The breakout sessions followed the invited presentations and were completed by noon of the third day. Summaries of the breakout groups were presented in a plenary session on the afternoon of the third day. The posters were on display throughout the entire workshop.

To keep the number of participants to a manageable number and to provide a constructive mix of physicists, government researchers, and thought-provoking innovators, an invitation-only format was used. Attendance was limited to about 90 participants due to the breakout sessions, where a maximum of 15 participants per each of the six groups was desired. For the overviews of emerging physics, established physicist were invited, including some with constructively pessimistic viewpoints. To foster collaboration between NASA and other government labs, several government researchers were invited. To provoke thought and discussion, poster papers were invited from individuals who had previously submitted materials to NASA on this subject. In total, 84 participants attended the workshop, including 16 from universities; 28 from industry; 11 from government labs including Los Alamos, Oak Ridge, Fermi, Brookhaven and the Air Force Research Labs at Edwards and Kirtland; 17 from NASA including from Glenn, Langley, Marshall, Johnson, and the Jet Propulsion Laboratory; and 12 students.

Since this workshop dealt with seeking breakthroughs in science, it asked participants to be *visionary*. Admittedly, these breakthroughs may turn out to be impossible, but progress is not made by conceding defeat. For the sake of promoting progress, participants were asked to entertain, for the duration of the workshop, the notion that these breakthroughs are indeed achievable. Simultaneously, however, this workshop looked for sound and tangible research approaches. Therefore, participants were also asked to be *credible* -- credible progress toward incredible possibilities.

To provide a list of next-step research tasks, the participants were divided into six breakout groups. Each of the three goals mentioned on page 1 were addressed by two of the six groups. Each group was led by a facilitator through a process designed to elicit a large number of creative ideas and then to evolve these ideas into candidate next-step research tasks. This process consisted of the following sequence:

(1) VISION: Participants were asked to assume a priori that the physics breakthroughs needed to create practical interstellar travel were achievable. They were asked to imagine that they were far enough into the future where these breakthroughs have been realized, and were asked to suggest ways that such feats were accomplished.

(2) ISSUES: Participants were asked to identify the critical unknowns and make-or-break issues associated with the ideas from Step-1, and to identify any curious effects (confirmed or unconfirmed) that may support the goals.

(3) NEXT STEPS: Participants were asked to propose the next-step experiments, theoretical analyses, or further theoretical developments that would be needed to

resolve the issues identified in Step-2. This included transforming *objections* into research *objectives*.

(4) EVALUATION: The ideas from Step-3 were scored using a spreadsheet containing the evaluation criteria shown below. This scoring was more of an experiment of the evaluation process than it was a genuine attempt at scoring the task ideas. As expected, none of the groups were able to score all of the task ideas they generated. However, each group selected a few representative tasks for presentation in the closing plenary session.

Relevance To Program:

- Directness to Program (Must seek propulsion relevant advances in physics)

- Magnitude of Potential Gains for Goal #1 (Mass) + Goal #2 (Speed) + Goal #3 (Energy)

Readiness:

- Level of Progress Achieved To Date (using scientific method levels as status metric)

- Testability (ease of empirical testing) (Note: experiments are considered closer than theory to becoming technology)

- Credibility: (As reflected by peer reviewed scientific literature)

- Minimum Credibility Criteria for Approaches Not in Peer Reviewed Literature *

- Fits credible data

- Advantageous to propulsion or power goals

- Discriminating test suggested

Research Task Factors:

- Level of Progress to be Achieved Upon Completion of Task (using scientific method levels as metric)

- Breadth of Work (experiment, theory, and/or comparative study)

- Triage (will it be done anyway or must this program support it?)

- Lineage (will it lead to further relevant advancements?)

- Time Required to Complete Task (reciprocal scoring factor)

- Funding Required (reciprocal scoring factor)

- Probability of Successful Task Completion (credentials and realism of proposal) *

* Due to time limitations during the workshop, these criteria were not used.

INVITED PRESENTATIONS

The invited presentations, from established physicists, covered many of the relevant areas of emerging physics. The intent of these presentations was to provide credible overviews of where we stand today in physics and introduce the unknowns and unresolved issues. Below is a short synopsis of these presentations in the order that they were presented. Where a related or equivalent work is available in the open literature, a reference is cited.

(1) Lawrence Krauss (Case Western Reserve University, Cleveland OH), *Propellantless Propulsion: The Most Inefficient Way to Fly?*: The physics behind manipulating spacetime for propellantless propulsion is reviewed. Even considering the possibilities of new physics, it is shown that such achievements would be probably impossible in practice. (Krauss 1995 and Pfenning 1997)

(2) Harold Puthoff (Institute for Advanced Studies at Austin, TX), *Can the Vacuum be Engineered for Spaceflight Applications?: Overview of Theory and Experiments*: Discusses the phenomena of electromagnetic vacuum fluctuations, its empirical

evidence, existing applications, and implications for breakthrough space propulsion and power. (Puthoff 1989, Cole 1993, and Haisch 1994)

(3) Raymond Chiao (University of California at Berkeley, CA), and A. Y. Steinberg, *Quantum Optical Studies of Tunneling Times and Superluminality*: Presents the experimental methods and results of measuring the tunneling time of a photon to cross a photonic band-gap tunnel barrier, where an effective tunneling speed of 1.7 times the speed of light is measured. The author concludes, however, that *information* did not travel faster than light. (Chiao 1994)

(4) John G. Cramer (University of Washington, Seattle, WA), *Quantum Nonlocality and Possible Superluminal Effects*: Discusses the quantum mechanics of *nonlocality*, which is often used to speculate about superluminal effects. Examples and unknowns are highlighted, including the transactional interpretation. (Cramer 86)

(5) Ronald J. Koczor, and David Noever (NASA MSFC, Huntsville, AL), *Experiments on the Possible Interaction of Rotating Type II YBCO Ceramic Superconductors and the Local Gravity Field*: Presents the status and interim results of experiments being conducted at MSFC to investigate claims of gravity effects in the vicinity of rotating superconductors in strong magnetic fields (Podkletnov 1992). Only static measurements have been completed to date, with inconclusive results (change of less than 2 parts in 10^8 of the normal gravitational acceleration) (Li 1997). Work continues toward measurements with rotating superconductors.

(6) Robert Forward (Forward Unlimited, Clinton, WA), *Apparent Endless Extraction of Energy from the Vacuum by Cyclic Manipulation of Casimir Cavity Dimensions*: Proposes a conceptual energy extraction method using cyclic dimensional changes of irregular Casimir cavities. This concept uses data on the energy densities of electromagnetic quantum fluctuations within irregular Casimir cavities, where portions of the data plots are double-valued (Ambjørn 1983 and Forward 1984).

(7) Bernhard Haisch (Lockheed Palo Alto CA) and A. Rueda, *The Zero-Point Field and the NASA Challenge to Create the Space Drive*: Proposes that the Newtonian F=ma equation can be derived from Maxwellís equations as applied to the electromagnetic vacuum fluctuations (Haisch 1994). The effective momentum of the vacuum fluctuations is speculated to be a possible basis of propulsion. The author also notes that negative mass is incompatible with this theory.

(8) Alfonso Rueda (California State University, Long Beach, CA) and B. Haisch, *Inertial Mass as Reaction of the Vacuum to Accelerated Motion*: Presents further investigations of the theories linking inertia to vacuum fluctuations. (Haisch 1994).

(9) Daniel C. Cole (IBM Microelectronics, Essex Junction, VT), *Calculations on Electromagnetic Zero-Point Contributions to Mass and Perspectives*: Challenges the theories linking inertia to vacuum fluctuations, but supports the idea of vacuum energy exchange (Cole 1993).

(10) Peter W. Milonni (Los Alamos National Labs, Los Alamos NM), *Casimir Effect: Evidence and Implications*: Reviews the empirical evidence used to support vacuum fluctuation theories, showing that source fields and macroscopic manifestations of intermolecular forces can also explain observed phenomena. (Milonni 1994).

(11) Hüseyin Yilmaz (Electro-Optics Technology Center, Winchester, MA), *The New Theory of Gravitation and the Fifth Test*: Compares the Einstein and Yilmaz theories with data of the gravitational perturbations on Mercury by the other planets. (Yilmaz 92).

(12) Arkady Kheyfets (Dept. of Mathematics, N. Carolina State Univ., Raleigh, NC) and Warner A. Miller, *Hyper-Fast Interstellar Travel via a Modification of Spacetime Geometry*: Addresses the key features and obstacles confronting the Alcubierre warp bubble and the Krasnikov tube for hyper-fast travel. Issues include the casual structure, weak and null-energy conditions as well as the violation of chronology protection. It is suggested that quantum gravity may be a more productive avenue to further investigate these possibilities and issues. (Alcubierre 94, Krasnikov 95, and Pfenning 97)

(13) Frank J. Tipler, III (Tulane University, New Orleans, LA), *Ultrarelativistic Rockets and the Ultimate Future of the Universe*: Presents a case that no new scientific discoveries are required to traverse the galaxy, provided that antiproton annihilation rockets are used and virtual (computerized) humans do the traveling.

(14) George Miley (University of Illinois, Urbana IL), *Possible Evidence of Anomalous Energy Effects in H/D-Loaded Solids -- Low Energy Nuclear Reactions*: Presents empirical evidence of excess energy, radiation emission, and transmutations of elements from experiments involving lattices loaded with deuterium by various

methods.

POSTER PAPERS

To provide imaginative material to help provoke discussion and research ideas, poster papers were solicited for the workshop. Selected posters were on display throughout the workshop, and are listed below, alphabetically by author. In those cases where a related or equivalent work is available in the open literature, a reference is cited. Some posters were based on peer reviewed publications while others were more adventurous and less rigorous. In pioneering work it can be difficult to distinguish between the ëcrazyí ideas that will one day evolve into breakthroughs, and the more numerous, genuinely crazy ideas. Even though many ideas proposed for this subject are likely to be incorrect, they can still be useful by provoking other, more viable, ideas. It was in this spirit that ideas beyond the conventional were invited for poster papers.

- D. Alexander (MSE Technology Applications, Inc.), *Replication of an Experiment Which Produced Anomalous Excess Energy.*
- C. Asaro (Molecudyne Research), *Special Relativity with Complex Speeds.* (Asaro 1996).
- J. D. Baxter (Student, ITT Technical Institute, Salt Lake City), *A Plan For Exceeding The Light Barrier.*
- E. W. Davis (National Institute for Discovery Science), *Wormhole Induction Propulsion (WHIP).*
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- M. N. Kaplan (Motorotor), R. D. Eagleton and N. W. Kantor, *Force Field Propulsion.*
- G. Landis (Ohio Aerospace Institute),*An Alcubierre Drive Using Cosmic String.*
- J. Maclay (Microfabrications Applications Lab, Univ. of Illinois), M. Serry, B. R. Ilic, P. Neuzil, and D. Czaplewski, *Use of AFM (Automatic Force Microscope) Methods to Measure Variations in Vacuum Energy Density and Vacuum Forces in Microfabricated Structures.* (Serry 1995).
- G. L. Matloff (New York Univ.),*The Zero-Point Energy (ZPE) Laser and Interstellar Travel.*
- M. G. Millis (NASA Glenn),*The Challenge to Create the Space Drive.* (Millis 1997b).
- J. M. Niedra, *Vacuum Fluctuations, Connectivity and Superluminal Physics for Interstellar Travel.*
- H. Ringermacher (GE Corp. Research and Development Ctr.), B. Cassenti and D. J. Leopold, *Search for Effects of an Electrostatic Field on Clocks in the Frame of Reference of Charged Particles.* (Ringermacher 1994).
- J. J. Roser, *Laboratory Scale Vacuum Energy Extraction Modeled on Weak Nuclear Force Reactions in a Spinning Black Hole System.*
- F. Rounds, *Anomalous Weight Behavior in* $YBa_2Cu_3O_7$ *Compounds at Low Temperature.*
- D. K. Sen (Grad Student, Dept. of Phys., Univ. of Washington), *Recent Results Concerning the Properties and Structure of the Electromagnetic Vacuum.*
- C. Seward (Electron Power Systems, Inc.), *Propulsion and Energy Generation Using the Electron Spiral Toroid.* (Seward 1996).
- G. Sobczak (Grad Student, Astronomy Dept., Harvard Univ.), *The Modified Casimir Force in a Uniformly Accelerating Reference Frame and in a Gravitational Field.*
- J. V. Vargas and D. G. Torr (Univ. of South Carolina), *Lurking Breakthrough Physics.* (Vargas 1991).
- E. L. Wall (Institute for Basic Research), *A First Tangible Step in the Quest for Hyperluminal Space Travel.*
- C. K. Whitney (Tufts Univ., Electro-Optics Technology Ctr.), *Challenging the Speed of Light.*
- J. F. Woodward (Dept. of Physics, California State Univ.), *Machís Principle and Impulse Engines: Toward a Viable Physics of Star Trek?* (Woodward

1992 and 1994).

- C. A. Yost (Electric Spacecraft Journal), *Electric Field Propulsion Concepts from Independent Researchers.*
- E. Zampino (NASA Glenn), *Can a Hyperspace Really Exist?*

CANDIDATE NEXT-STEP RESEARCH APPROACHES

Based on the invited presentations, poster papers, and the ideas generated during the breakout sessions, several next-step research approaches were identified and are presented next. These are arranged according to the three program goals and highlight the intriguing phenomena and theories, critical issues, and candidate next-step approaches for each program goal. Regarding the specific task ideas generated during the breakout sessions, about 80 task ideas were collected. These have not yet been fully reviewed, but many are integrated into the discussions below.

Toward Goal 1 - Eliminating Propellant Mass

It is known that gravity, electromagnetism and spacetime are coupled phenomena. Evidence includes the bending of light, the red-shifting of light, and the slowing of time in a gravitational field as illustrated in Figure 1. This coupling is most prominently described by general relativity (Misner 1973). Given this coupling and our technological proficiency for electromagnetics, it has been speculated that it may become possible to use electromagnetic technology to manipulate inertia, gravity, or spacetime to induce propulsive forces (Millis 1997b). Another phenomena of interest is the Casimir Effect, Figure 2, where closely spaced plates are forced together, presumably by vacuum fluctuations (Lamoreaux 1997). One explanation is that this force is the net radiation pressure of the virtual vacuum fluctuation photons, where the pressure is greater outside the plates than within, since wavelengths larger than the plate separation are excluded. The force is inversely proportional to the 4th power of the distance. Even though this effect can be explained by various theories (Milonni 1994), the idea that the vacuum might create these forces leads to speculations that an *asymmetric* vacuum effect, if possible, could lead to a propulsive effect (Millis 1997b). There are many unsolved issues regarding these speculations, including whether these phenomena can lead to controllable net-force effects and whether such effects can be created, even in principle, without violating conservation of momentum and energy (Millis 1997b).

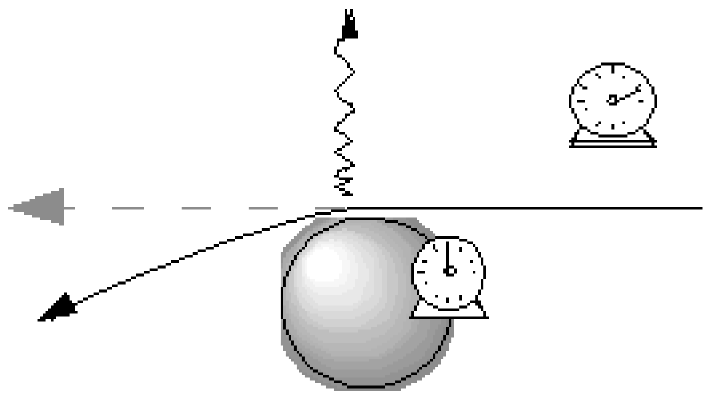

FIGURE 1. Coupling of Gravity, Spacetime, and Electromagnetism.
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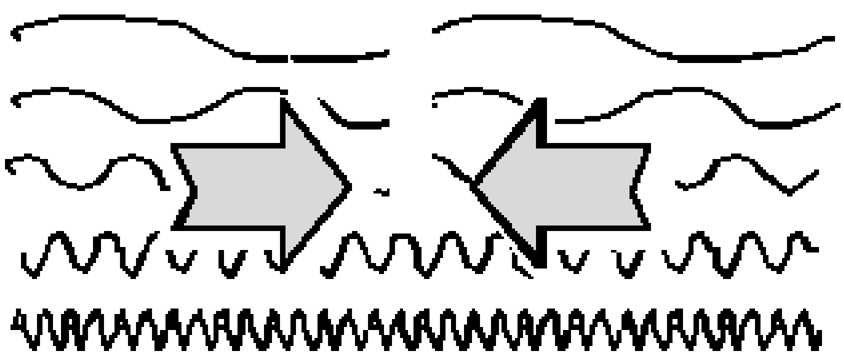

FIGURE 2. The Casimir Effect
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Although it is presently unknown if such propellantless propulsion can be achieved, several theories have emerged that provide additional research paths. It should be noted that all of these theories are too new to have either been confirmed or discounted, but their potential utility warrants consideration. This includes negative mass propulsion (Bondi 1957), theories that suggest that inertia and gravity are affected by vacuum fluctuations (Puthoff 1989 and Haisch 1994), and numerous other theories about the coupling between matter, electromagnetism, and spacetime (Dinowitz 1996, Froning 1997, Ringermacher 1994, Vargas 1991, Woodward, 1992, and Yilmaz 1992). Another recent development, which has yet to be credibly confirmed or discounted, is where anomalous weight changes are observed over spinning superconductors (Podkletnov 1992).

During the workshop these possibilities were discussed with an emphasis on experimental verification. A poster by Forward suggested a search for evidence of negative mass based on recent astronomical data (da Costa 1996). The posters of Dinowitz, Froning, Ringermacher, and Woodward all offered experiments to test their theories. Several experiments were suggested to test the theories linking inertia to vacuum fluctuations, including experiments described in existing literature (Forward 1996). And interest was expressed in continuing the experiments to test the claims of weight changes over spinning superconductors (Li 1997).

Toward Goal 2 - Achieving the Ultimate Transit Speed

Special relativity states that the speed of light is an upper limit for the motion of matter through spacetime. Recently, however, theories using the formalism of general relativity have suggested that this limit can be *circumvented* by altering *spacetime* itself. This includes wormhole and warp drive theories. A wormhole is a shortcut created through spacetime (Morris 1988 and Visser 1995), as illustrated in Figure 3, where a region of spacetime is warped to create a shorter path between two points. A warp drive involves the expansion and contraction of spacetime to propel a region of spacetime faster than light (Alcubierre 1994). Figure 4 illustrates the Alcubierre warp drive, showing the opposing regions of expanding and contracting spacetime that propel the center region.

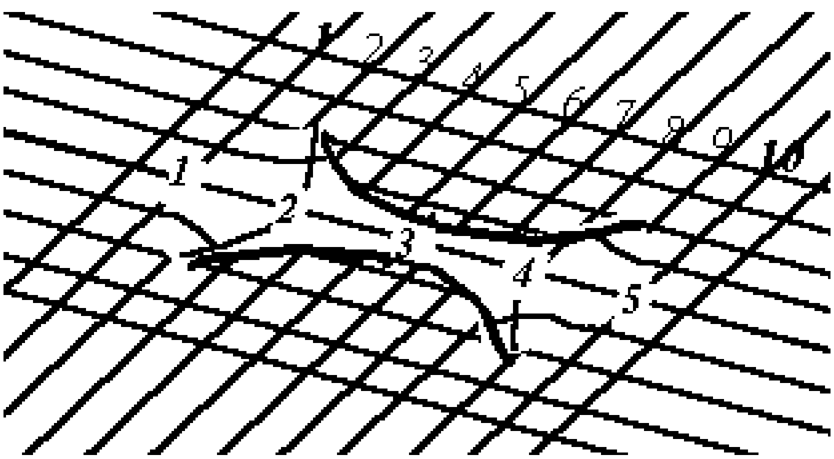

FIGURE 3. Wormholes - Spacetime Shortcuts.
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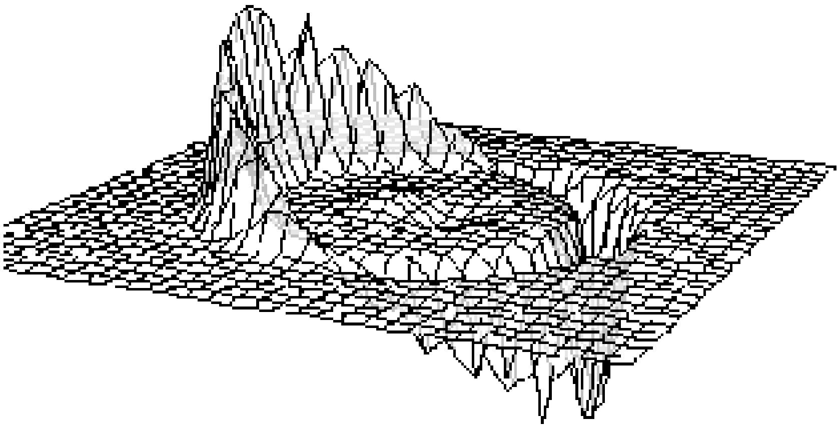

FIGURE 4. The Alcubierre Warp Drive
Note: Figure did not transcribe correctly from original report.

It has also been suggested that the light speed limit could be exceeded if velocities could take on imaginary values (Asaro 1996). In addition, there are theories for nonlocality from quantum physics that suggest potentially superluminal effects (Cramer 1986). These theories not only present challenging physics problems, but are intriguing from the point of view of future space travel. Do these theories represent genuinely possible physical effects, or are they merely mathematical curiosities?

In addition to theories, there are some intriguing experimental effects. Photons have been measured to tunnel across a photonic band-gap barrier at 1.7 times the speed of light (Chiao 1994). Even though the author concludes that *information* did not travel faster than light, the results are intriguing. During the workshop several suggestions were made to conduct similar experiments using matter rather than photons to unambiguously test the *information* transfer rate. In addition, recent experiments of the rest mass of the electron antineutrino have measured an imaginary value (Stoeffl 1995). Even though this result is attributed to possible errors, an imaginary mass value is a signature characteristic of a tachyon. Tachyons are hypothetical faster-than-light particles. In the workshop it was suggested to revisit this and other similar data to determine if this can be credibly interpreted as evidence of tachyons. It was also pointed out that other experiments have been suggested to search for evidence of tachyons (Chiao 1996).

The notion of faster-than-light travel evokes many critical issues. These were summarized in the presentation by Kheyfets. Issues include causality violations, the requirement for negative energy, and the requirement for enormous energy densities to create the superluminal effects. Suggestions were made during the workshop for a number of theoretical approaches to address these issues, including the use of quantum gravity to study the wormhole and warp drive concepts.

Toward Goal 3 - Discovering New Modes of Energy Production

Since the first two breakthroughs could require breakthroughs in energy generation, and since the physics underlying the propulsion goals is closely linked to energy physics, it is also of interest to discover fundamentally new modes of energy generation. The principle phenomena of interest for this category is, again, the vacuum fluctuations. It has been theorized that this energy can be extracted without violating conservation of energy or any thermodynamic laws (Forward 1984, Cole 1993). It is still unknown if this vacuum energy exists as predicted, how much energy might be available to extract, and what the secondary consequences would be of extracting vacuum energy.

At the workshop, the techniques described in the posters of Maclay (Serry 1995), Erickson, and Sen were suggested to investigate the energy extraction concepts described in the poster of Erickson and by the presentation by Forward. These techniques involve the use of micromechanical structures. Not only are micromechanical structures an emerging technology, but the dimensions of such structures are similar to the dimensions required for Casimir effects. Also, should any viable device be engineered, these methods hold promise for high-volume manufacturing.

On a more conventional vein, ideas were raised at the workshop by Tipler and others for seeking alternative methods of antimatter production. Also, the poster by Seward presented a novel energy storage device involving toroidal plasmas (Seward 1996).

PROGRAM STATUS AND NEXT STEPS

The Breakthrough Propulsion Physics Program was established in 1996 as part of the Advanced Space Transportation Plan (ASTP) managed by MSFC (Millis 1997a). A government Steering Group containing volunteers from various NASA centers, DoD and DoE laboratories and led by the Glenn Research Center, has been established to guide this program. This includes the development of the research solicitation and selection criteria used during the workshop, and which are being refined for future evaluations of research proposals.

The first major milestone of the program was this kick-off workshop. A publicly available Conference Proceedings is being assembled to fully document the results. The list of task ideas generated during the workshop will be used to advocate for funding to support this research.

Once funded, this program plans to use an annual NASA Research Announcement (NRA) to solicit and support research tasks. This solicitation will be open to academia, industry, government labs, and NASA centers. Selection will be via a peer review process led by the Steering Group and using the prioritization criteria to provide an initial ranking. Because it is too early to focus on a given approach, it is anticipated that multiple, different approaches will be supported from the top ranking candidates. Proposed tasks should be of relatively short duration (1-3yrs), modest cost ($50 to $150K), and traceable to at least one of the three program goals.

The next step of the program, with or without funding, is to reopen participation to the broader set of government, university and industry researchers. An internet site has been established as a first step to begin this collaboration (http://www.GRC.nasa.gov/WWW/bpp/). Also, a limited access site is envisioned to contain works in progress, more in-depth annotated bibliographies, and allow on-line discussions. Access will be limited to a Contributor Network selected by the Steering Group. The process for nominating and selecting Contributor Network members has not yet been established.

CONCLUSIONS

New theories and laboratory-scale effects have emerged in the scientific literature which provide new approaches to seeking major propulsion breakthroughs. During the recent workshop, many of these new approaches were reviewed, and about 80 specific research task ideas were generated for making progress toward propulsion breakthroughs. A peer review system has been drafted that can be used to rank these and other future proposals.

Acknowledgments

Special thanks is owed to the Glenn Research Center *volunteers* who helped make this workshop a success: Obasi Akan, Sheila Bailey, Michael Binder, David Chato, Dane Elliott-Lewis, Cynthia Forman, James Giomini, Jon Goldsby, Scott Graham, Al Juhasz, Geoffrey Landis, Grace Scales, Gary Scott Williamson, Natalie Woods, Ed Zampino, and especially to Joe Hemminger for arranging the equipment and volunteers for the breakout sessions. Special thanks is also owed to the *volunteer* members of the BPP Steering Group, especially to Frank Mead. In addition, thanks is owed to the Honorable Dennis Kucinich for his opening remarks, and to the NYMA Inc. staff for smoothly handling the workshop logistics; Dr. Richard Ziegfeld, Linda Oliver, and John Toma.

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Breakthrough Propulsion Physics Project

WHY NOW

(Originally written in 1996)

There comes a point when it is time to seek the next revolutions in technology. That point is when the existing methods are reaching the limits of their performance and new possibilities are emerging for alternative methods that might exceed those limits. The limits of ground transportation were surpassed by aircraft. The altitude limits of aircraft were surpassed by rockets. And now, rocket technology is approaching the performance limits of its underlying physical principles. To break through the limitations of rockets, it is necessary to search for alternative propulsion methods with different physical principles. New theories and physical effects have emerged in recent scientific literature that may provide such alternatives. To shape these emerging possibilities to answer the propulsion needs of NASA, the Breakthrough Propulsion Physics Project was established.

Rocket technology is fundamentally limited by its need for propellant. The farther, faster, or more payload carried, the more propellant that is required. This limit **cannot** be overcome with *engineering* refinements. This limitation is based on the underlying physical principles of all rocket propulsion - the very *physics* of its operation. Because a rocket's reaction mass, its propellant, must be carried with the rocket, propellant needs rise exponentially with increases in payload, destinations, or speed. This is true for all forms of rocket technology, from the chemical engines of the Shuttle, through all envisioned nuclear rockets, and even electric ion thrusters. For human journeys into orbit, to the Moon, or to Mars, rocket technology is adequate. For robotic probes to the outer planets of our Solar System, rocket technology is also adequate. However, to dramatically reduce the expense of these journeys or to journey beyond these points in a reasonable time, some new, alternative propulsion physics is required.

Recent advances in science have reawakened consideration that new propulsion mechanisms may lie in wait of discovery. For example, recent experiments and Quantum theory have revealed that space might contain enormous levels of vacuum electromagnetic energy. This has led to questioning if this vacuum energy can be used as an energy source or a propulsive medium for space travel. Next, new theories speculate that gravity and inertia are electromagnetic effects related to this vacuum energy. It is known from observed phenomena and from the established physics of General Relativity that gravity, electromagnetism, and spacetime are inter-related phenomena. These ideas have led to questioning if gravitational or inertial forces can be created or modified using electromagnetism. Also, theories have emerged about the nature of spacetime that suggest that the light-speed barrier described by Special Relativity might be circumvented by altering spacetime itself. These "wormhole" and "warp drive" theories have reawakened consideration that the light-speed limit of space travel may be circumvented. Today, it is still unknown whether these emerging theories are correct and, even if they are correct, if they will become viable candidates for creating propulsion breakthroughs.

To space technologists such emerging possibilities are of keen interest. The propulsive implications of such emerging science is not a major concern to the general scientific community, however. Instead, much of modern physics is focused on understanding the origins and age of the universe, answering the question of the missing matter of the universe, and probing the physics of black holes and high-energy particle interactions.

In 1990, a team of Lewis Research Center volunteers began an effort to formulate the questions and search for ideas from the scientific literature related to the possibility of creating a "field-drive" propulsion. This informal and unofficial group, called The "Space-Coupling Propulsion and Power Working Group, conducted some experiments and theoretical investigations, and forged collaborations with other scientists and engineers from other NASA centers, other government laboratories, universities, and industry. In particular, this group helped create a growing awareness of the opportunities emerging from science and the need to apply these opportunities to overcome the limitations of rocket technology.

In 1996, following a re-organization of NASA, the Marshall Space Flight Center was tasked to formulate a comprehensive strategy for advancing propulsion technology for the next 25 years. This strategy, called the Advanced Space Transportation Program (ASTP), spans the nearer-term technology improvements for launchers all the way through seeking the breakthroughs that could revolutionize space travel and enable interstellar voyages. To address the most visionary end of this scale, the Marshall Space Flight Center sought out the work of this Lewis Research Center team. Marc G. Millis, the leader of the Lewis team, assembled a group of government, university, and industry researchers to propose the Breakthrough Propulsion Physics Project, as a part of this Advanced Space Transportation Program. In July, 1996, this Breakthrough Propulsion Physics Project was formally established.

The Breakthrough Propulsion Physics Project supports the scientific study of motion through space with the goal of discovering breakthrough means to propel spacecraft farther, faster, and more efficiently. Specifically, this project aims to produce near-term, credible, and measurable progress toward conquering the following 3 breakthrough goals:

> (1) MASS: Discover new propulsion methods that eliminate or dramatically reduce the need for propellant. This implies discovering fundamentally new ways to create motion, presumably by interactions between matter, fields, and spacetime, including the possibility of manipulating gravity or inertia.
>
> (2) SPEED: Discover how to attain the ultimate transit speed to dramatically reduce travel times. This implies discovering a means to move a vehicle at or near the actual maximum speed limit for motion *through space* or by the *motion of spacetime itself* (if possible, this means *circumventing* the light-speed limit).
>
> (3) ENERGY: Discover fundamentally new modes of onboard energy generation to power these propulsion devices. This third goal is included since the first two breakthroughs could require breakthroughs in energy generation, and since the physics underlying the propulsion goals is closely linked to energy physics.

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Breakthrough Propulsion Physics Project

The following essay was adapted from:
Millis, M. G., "**Breaking Through to the Stars**", In *Ad Astra, The Magazine of the National Space Society*, Vol. 9, N. 1, pp. 36-40, (Jan-Feb. 1997).

ENABLING INTERSTELLAR VOYAGES

Based on projections of current technology, it is feasible to send a probe to one of our neighboring stars, but it is still prohibitively expensive. This was the conclusion of a conference hosted by Ed Belbruno in New York City in September 1994. The conference, titled "Practical Robotic Interstellar Flight: Are We Ready?," examined concepts for interstellar propulsion that are based on firmly established science. It covered many concepts including light sails, magnetic sails, and nuclear rockets. Although these methods are technologically feasible, they would still require enormous investments to bring them to fruition. To bring down the cost of developing interstellar technologies, conference attendees suggested that less expensive "pre-stellar" missions should be used as starting points, missions such as sending probes to explore the Kuiper Belt or Oort Cloud, or sending a telescope beyond 550 AU to use the gravitational lensing effect of our own Sun for astronomy.

There is an entirely different approach, however. Rather than limit ambitions to foreseeable solutions, why not seek the solutions to the original ambition? In this case the ambition is to travel comfortably and affordably to our neighboring star systems. As already stated, this is beyond the ability of our *foreseeable* solutions -- solutions based on text book science and projected technology. To seek the solutions to make interstellar travel practical and affordable it is necessary to search *beyond* current understanding -- to go back to the sciences from which technology emerges and search for the new science which could lead to propulsion breakthroughs -- the kind of breakthroughs that would make interstellar travel practical.

Challenges of Interstellar Propulsion

First, let's look at what breakthroughs are required before we can travel comfortably to our neighboring stars. Our first challenge is *mass*, propellant mass. Today's spacecraft use rockets and rockets use large quantities of propellant. As propellant blasts out of the rocket in one direction, it pushes the spacecraft in the other -- Newton's third law. The farther or faster we wish to travel, the more propellant we'll need. For long journeys to neighboring stars, the amount of propellant we would need would be enormous and prohibitively expensive. For example, to send a vehicle the size of the Space Shuttle, and equipped with the same chemical rockets, to our nearest star at a leisurely pace of ten centuries, we would need about 10^119 kg of propellant. Compare that with 10^55 kg, which is an estimate of all the mass in the universe (estimate based on models for a closed, finite universe). Even if we used all the mass in the universe, we would not be able to fuel this journey. With the best rockets conceivable, say antimatter rockets or ion engines with an exhaust velocity two hundred times greater than for current rockets, we would still need over 500 supertanker-sized propellant tanks just to fly past our nearest star within a century. If we wanted that same spacecraft to actually stop when it got to its destination, we would need to use that 500 supertankers for braking and would need another 300 *million* supertankers of propellant to propel the vehicle toward the star along with all its braking propellant. Clearly, rockets are NOT the way to go to the stars. We need to find some fundamentally new mode of travel that requires little or NO propellant. This implies the need to find some way to modify gravitational or inertial forces or to find some means to push against the very structure of spacetime itself.

Our next challenge is *speed*. Even though the breakthrough of eliminating propellant would greatly boost how quickly we could travel in space, to reach interstellar destinations in comfortable time frames (say, within a term of congress), would require another breakthrough in physics. The fastest thing we know of is light. Yet, even at light speed it would take almost 9 years for a round trip journey to our nearest star system. The mission's financial backers might want a quicker return on their investment. And this 9 year time table assumes that we are *at* light speed. For objects like people and spacecraft that are built of matter rather than photons, the journey would be even slower. To travel to our neighboring stars in comfortable time frames, it is desirable to have the physics breakthrough that allows us to travel faster than the speed of light. Most scientists say this is impossible; others are more optimistic.

Our third big challenge is *energy*. Even if we had a non-rocket space drive that could convert energy directly into motion without propellant, it would still require a lot of energy. Sending a Shuttle-sized vehicle on a 50 year one-way trip to visit our nearest neighboring star (subrelativistic speed) would take over 7 x 10^19 Joules of energy.

This is roughly the same amount of energy that the Space Shuttle's engines would use if they ran continuously for the same duration of 50 years. To overcome this difficulty, it is desired to have a breakthrough where we can take advantage of any energy in space or a breakthrough in energy production physics.

Fortunately, science and technology continue to evolve. In just the last few years, there have been new, intriguing developments in the scientific literature. Although it is still too soon to know whether any of these developments can lead to the desired propulsion breakthroughs, they do provide new clues that did not exist just a few short years ago. This NASA project will determine if and how these emerging possibilities can be applied to the goal of creating the desired propulsion breakthroughs.

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Date: June 27, 2000

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Typical question from the public:

"When can we build something like this?"

Answer:

"This is not in the *foreseeable* future. Today it is still unknown ***if*** such visions are even achievable ...

but ...

new possibilities continue to emerge from science. NASA established the '***Breakthrough Propulsion Physics Project***' to pursue these possibilities."

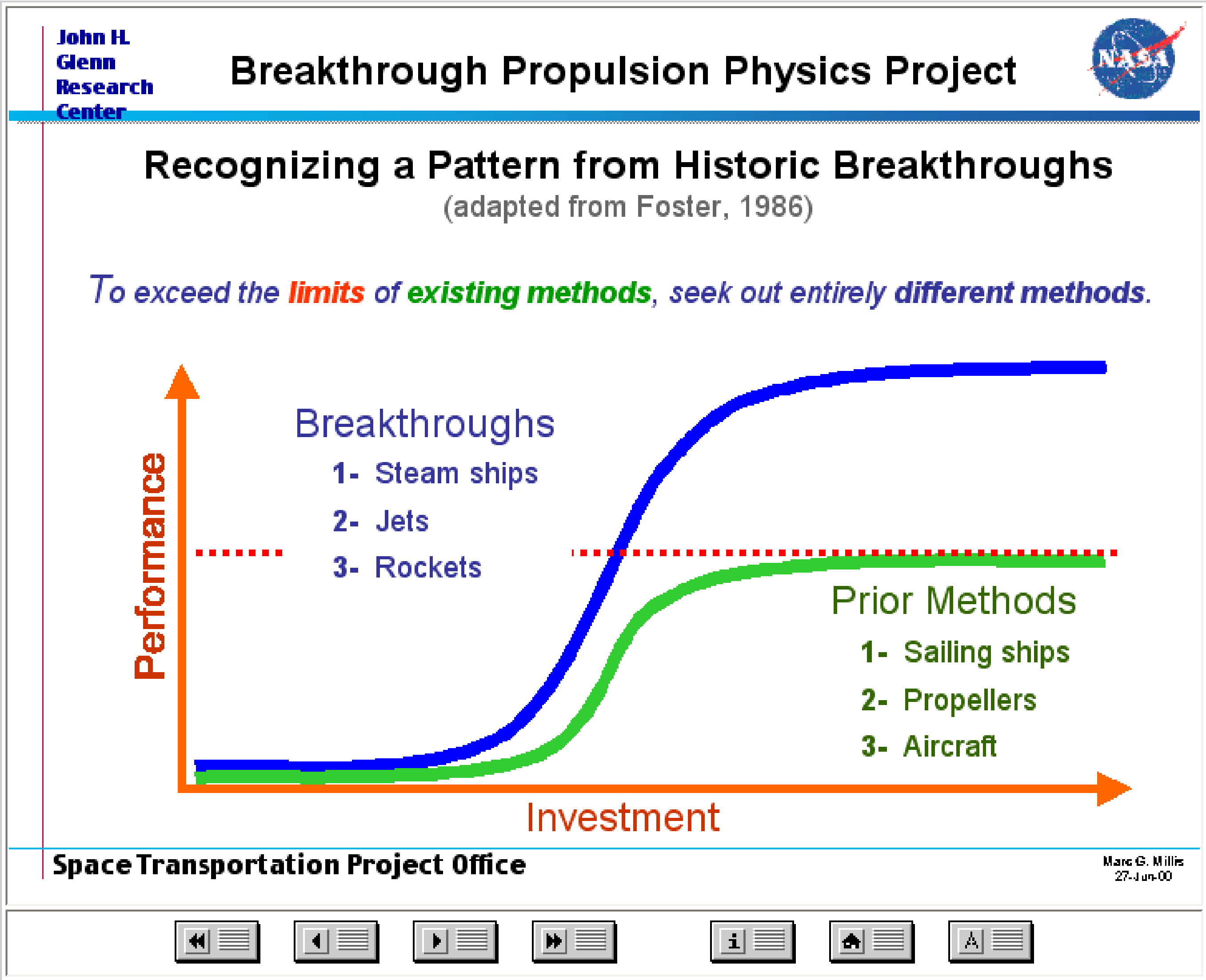
NASA
Breakthrough Propulsion Physics Project

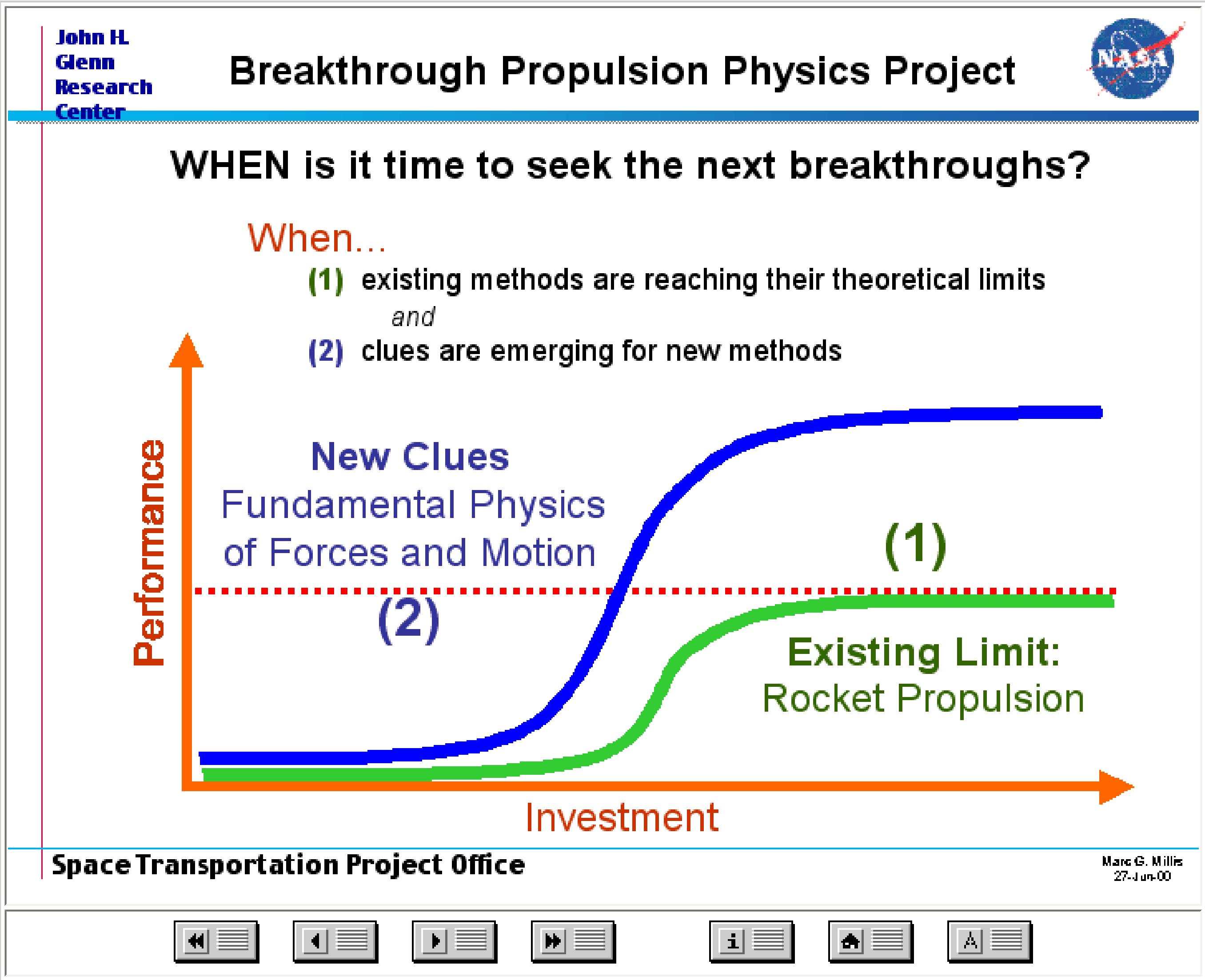
- An Introduction -

Marc G Millis
Glenn Research Center, Cleveland Ohio
2000 - April

Contents:

- Lessons from prior breakthroughs
- Project approach and scope
- What's been done so far
- Currently supported research
- What's next ?


John H. Glenn Research Center
Breakthrough Propulsion Physics Project
NASA
Recognizing a Pattern from Historic Breakthroughs
(adapted from Foster, 1986)
To exceed the limits of existing methods, seek out entirely different methods.
Performance
Breakthroughs
1- Steam ships
2- Jets
3- Rockets
Prior Methods
1- Sailing ships
2- Propellers
3- Aircraft
Investment
Space Transportation Project Office
Marc G. Millis
27-Jun-00



John H. Glenn Research Center
Breakthrough Propulsion Physics Project
WHEN is it time to seek the next breakthroughs?
When...
(1) existing methods are reaching their theoretical limits
and
(2) clues are emerging for new methods
New Clues
Fundamental Physics
of Forces and Motion
(1)
(2)
Existing Limit:
Rocket Propulsion
Performance
Investment
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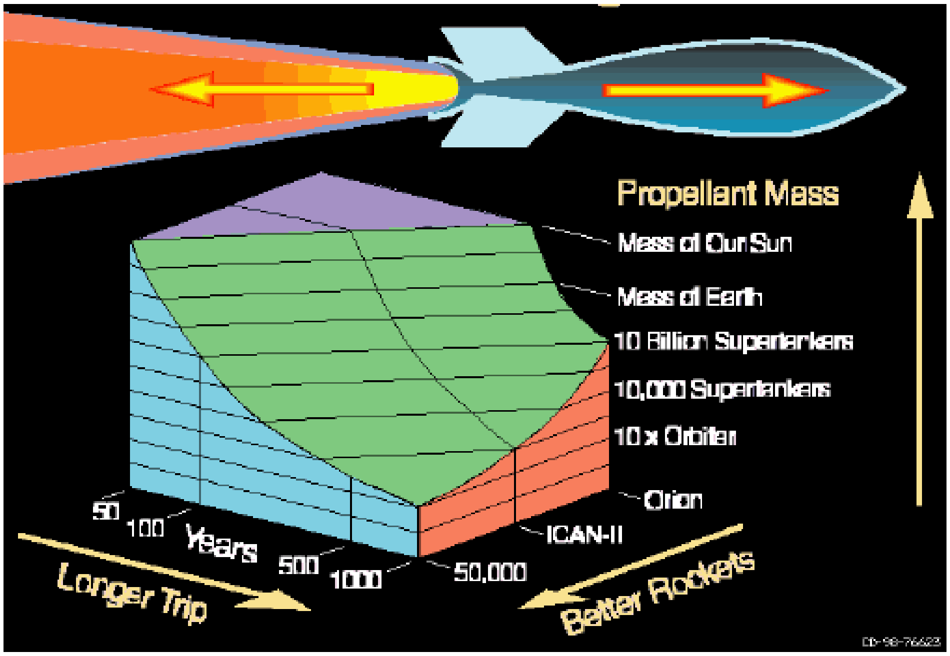
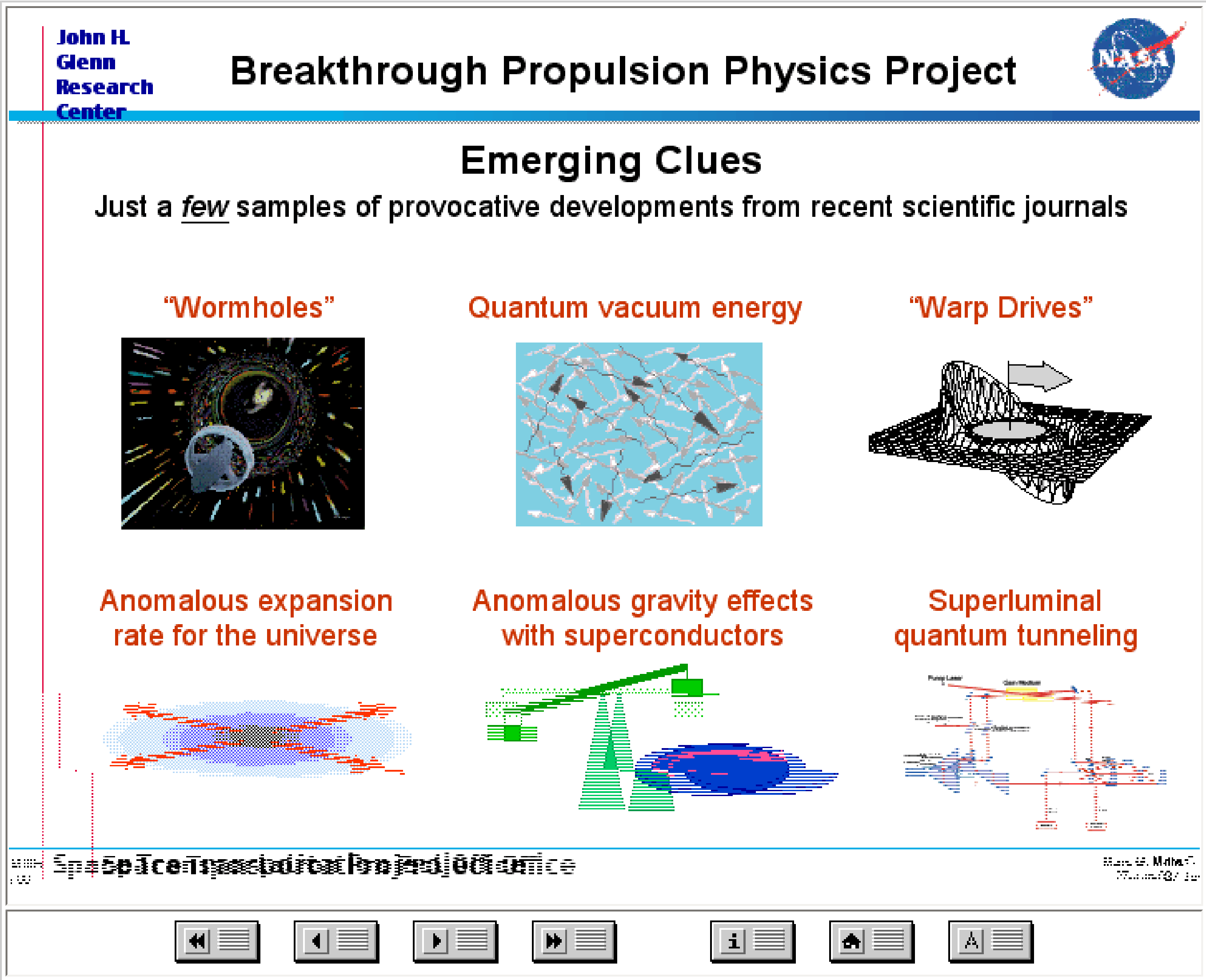
Fundamental Limit of Rockets - PROPELLANT

(example: Propellant required to fly mass of Shuttle Orbiter past 4.3 Light-years)

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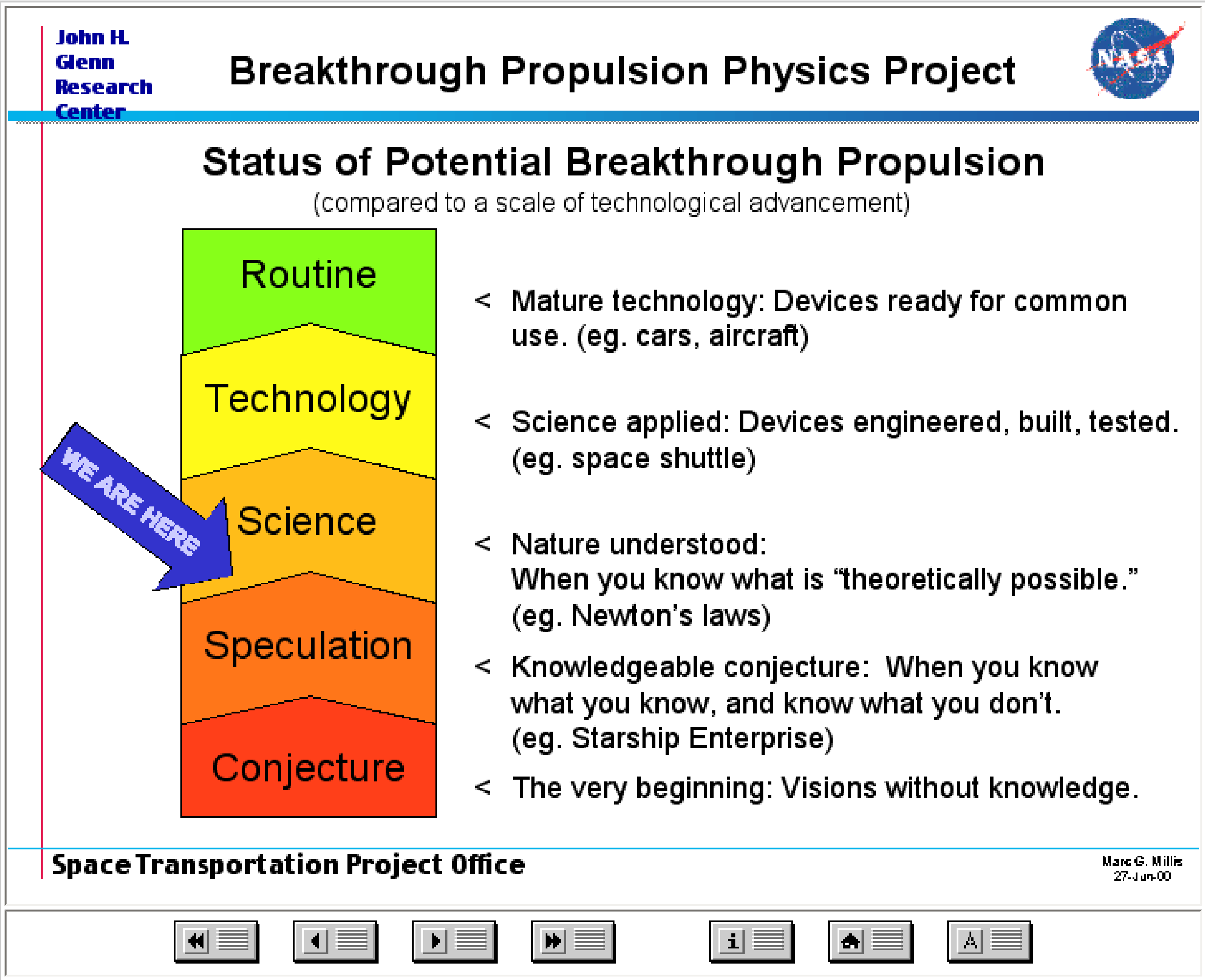
Breakthrough Propulsion Physics Project
Emerging Clues
Just a *few* samples of provocative developments from recent scientific journals
"Wormholes"
Quantum vacuum energy
"Warp Drives"
Anomalous expansion rate for the universe
Anomalous gravity effects with superconductors
Superluminal quantum tunneling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Breakthrough Propulsion Physics Project
Status of Potential Breakthrough Propulsion
(compared to a scale of technological advancement)
Routine
Technology
Science
Speculation
Conjecture
WE ARE HERE
Mature technology: Devices ready for common use. (eg. cars, aircraft)
Science applied: Devices engineered, built, tested. (eg. space shuttle)
Nature understood: When you know what is "theoretically possible." (eg. Newton's laws)
Knowledgeable conjecture: When you know what you know, and know what you don't. (eg. Starship Enterprise)
The very beginning: Visions without knowledge.
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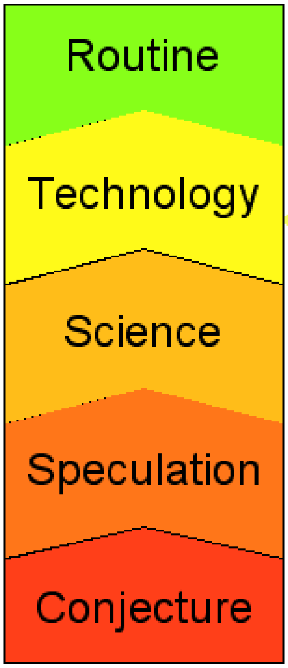
Breakthrough Propulsion Physics Project

Space Technology Readiness Levels

(for comparison)



TRL 7 Engineering model tested in space.

TRL 6 Prototype / engineering model tested in relevant environment.

TRL 5 Component / breadboard tested in relevant environment.

TRL 4 Critical function / characteristic demonstration.

TRL 3 Conceptual design tested.

TRL 2 Conceptual design formulated.

TRL 1 Basic principles observed and reported.

Hord, M., CRC *Handbook of Space Technology: Status & Projections* CRC Press, FL, © 1985

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PPT Slide

Emerging Clues

Just a few samples of provocative developments from recent scientific journals

“Wormholes”

Anomalous expansion rate for the universe

“Warp Drives”

Quantum vacuum energy

Superluminal

quantum tunneling

Anomalous gravity effects with superconductors

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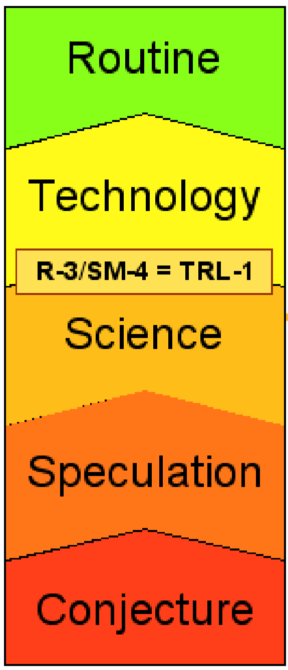
Measuring Pre-Technology Progress



First, specify the degree of relevance of the emerging science, and then specify the progress achieved within this relevance using the Scientific Method levels.

Relevance of science topic (as readiness levels):

R-3 Directly relevant to a technologically desired effect
R-2 Critical make-break issue underlying the desired effect
R-1 Underlying general physics

Scientific Method (as readiness levels):

SM-4 Hypothesis empirically confirmed / dismissed
SM-3 Hypothesis proposed
SM-2 Data collected
SM-1 Problem formulated (identify relevant knowledge gaps)
SM-Ø Pre-science:
- Anomalous effect noted, or
- Correlation between goal & knowledge recognized.

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Breakthrough Propulsion Physics Project

Scope of Effort

To put this into perspective

BPP Personnel: **1 person / year** (i.e., Millis)

BPP Funding: **$685K Total … so far**
Summed 1996 - 2000 and all tasks combined
(does not include salary of the 1 person)

All other support has been volunteered from scientists, engineers, and managers across the USA and the world.

Some other parallel efforts also exist, but total $ unknown.

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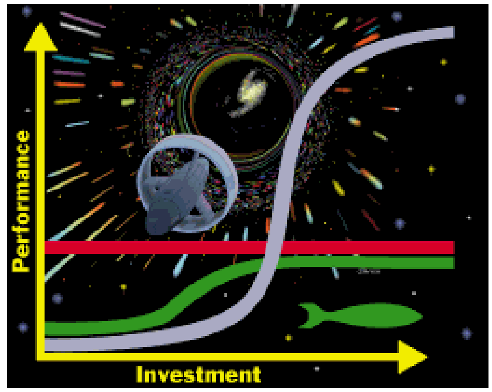
25-Jul-00

Breakthrough Propulsion Physics Project

Project Objective

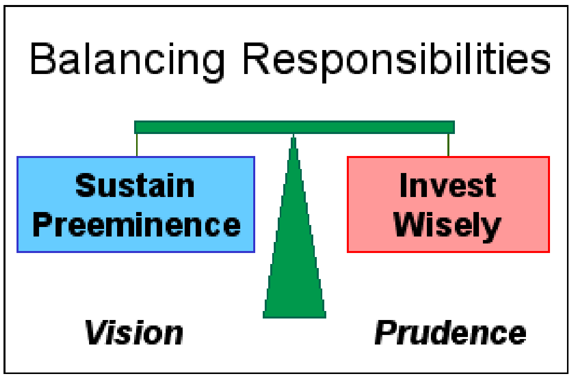
Produce incremental, credible, and measurable progress toward conquering the ultimate breakthroughs needed to revolutionize space travel and enable interstellar voyages ...



... by advancing ***science*** to provide new foundations for breakthrough technology.

Breakthrough Propulsion Physics Project

"… incremental, credible, and measurable progress …"



- Focus on immediate make-or-break issues.
- Sustain progress as a series of short-term, incremental tasks.
- Define "success" as acquiring credible knowledge rather than requiring a breakthrough.
- Explore multiple, divergent approaches simultaneously.
- Consider visionary speculations, yet tempered with credible methods, and built on credible foundations.
- Measure progress using the scientific method.

Vision with Credibility

- No jumping to conclusions; supportive nor dismissive
- Open minded to possible successes and impossibilities
- Converting *objections* into research *objectives*

Visionary	+	Credible
- Entertain that it can be done		- Be *constructively* skeptical
- Imagine the possibilities		- Identify unsolved physics
- Draw on inspirations		- Build on known science
- Pattern after past successes		- Aim toward *testable* concepts
		- use scientific method

Breakthrough Propulsion Physics Project

"… the ultimate breakthroughs needed …"

1. **Mass:** Discover new propulsion methods that eliminate or dramatically reduce the need for propellant.

2. **Speed:** Discover how to circumvent existing limits to dramatically reduce transit times.

3. **Energy:** Discover new energy methods to power these propulsion devices.

These goals are **THE** breakthroughs needed to conquer the presently *impossible* ambition of human interstellar exploration.

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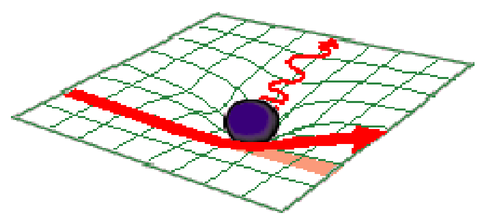
Breakthrough Propulsion Physics Project

Physics of Interest

- Coupling of fundamental forces and spacetime (Gravity, Electromagnetism, etc).
- Space from the perspective of providing energy or reaction mass for space flight.
- Motion of matter and energy through spacetime.
- Interactions *with* spacetime (includes “warp drives,” “wormholes,” or other transport-related theories).
- Energy exchange mechanisms.
- Anomalous physical effects.



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27-Jun-00

Project Implementation

As a sequence of prudent, conditional steps

(1) **1996**
Define goals and determine if sufficient scientific foundations exist (*YES*).

(2) **1996**
Network to identify possibilities and foster collaborations (*Continuing*).

(3) **1997**
Determine if affordable candidate research tasks exist (*YES*).

(4) **1999-2000**
Solicit , select, and support 1st round of research tasks (5 tasks so far).

(5) **≥ 2001**
Assess progress upon completion of 1st round of sponsored research (*TBD*).

Now revising plans to accommodate greater than anticipated possibilities and interest.

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Breakthrough Propulsion Physics Project

Networking Through Conferences and Workshops

- 1997 Kick-Off Assessment Workshop, **80** candidate tasks identified. (CP-1999-208694)
- 1998 STAIF 10 papers (AIP-420 pp.1435-1461, 1502-1534)
- 1998 Physics Lecture Series (MSFC & GRC-OAI)
- 1998 AIAA Joint Propulsion Conference 7 papers (AIAA 98-3136 … 98-3143)
- 1999 STAIF 23 papers (AIP-458 pp. 875-937, 954-1062)
- 1999 AIAA Joint Propulsion Conference, 5 papers (AIAA 99-2143 ... 99-2147)
- 2000 STAIF 19 papers (AIP-504 pp. 998-1132)

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Breakthrough Propulsion Physics Project

1997 Kick-Off Workshop

To determine if affordable candidate research tasks exist

- **What's new? - reviewed emerging physics**
  - **14** established physicists gave overviews of recent scientific literature
  - Pessimistic presentations included for balance
- **Provoked thoughts using 30 Poster Papers**
  - Innovators with next-step ideas
  - 1/3 Based on peer literature, 1/3 clearly "more adventurous" (too many)
- **Produced a list of 80 candidate next-step research tasks**
  - Used facilitator-run breakout sessions
  - Sought task ideas that focus emerging physics toward program goals
- **84 Participants**

  28 Industry, **16** University, **12** Students, **11** Other Government Labs, **17** NASA

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27-Jun-00

Research Selection Criteria

* Mandatory Criteria

Technical Relevance:

- A* Directness to program (must seek advances in physics that are relevant to propulsion or power).
- B* Magnitude of potential gains for Goal #1 [Mass] + Goal #2 [Speed] + Goal #3 [Energy].
- C Lineage (will it lead to further relevant advancements?)
- D Status to be achieved upon completion of task (using scientific method levels as a metric)
- (D-E)* Magnitude of progress to be gained by the work (using scientific method levels as a metric).

Probability of Success (credibility filters) **:**

- F* Based on credible foundations (references must be cited)
- G* Compared with current credible approaches (references must be cited)
- H* Must be, or be leading toward, a credible discriminating test.
- I* Probability of successful task completion (based on credentials and realism of proposal)

Note: Negative test results are considered progress

Programmatic Merit:

- J Breadth of work (experiment, theory, and/or comparative study)
  [Note: experiments are considered closer than theory to becoming technology, and are ranked higher]
- K Triage (will it be done anyway or must this program support it?)
- L Time required to complete task (reciprocal scoring factor)
- M Funding required (reciprocal scoring factor)

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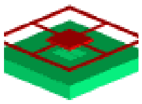
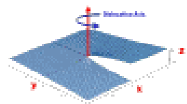
Breakthrough Propulsion Physics Project

NRA Task Awards

1. **Independent test of Woodward's transient inertia effect.**
   If genuine, this effect may enable thrusting directly against spacetime itself.
   Dr. J. Cramer, U. of Washington, Seattle, C-78671-K, Final report due March 2001, R-3 / SM-3 -> SM-4.

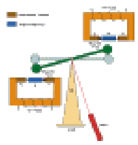


2. **Investigation of quantum vacuum energy.**
   Addresses make-break issues of vacuum energy: existence, magnitude, and transferability.
   Dr. Jordan Maclay, Quantum Fields, WI, and MEMS Optical, Huntsville, AL,
   NAS3-00093, Final report due Dec 2002, R-2-3 / SM-3 -> SM-4.

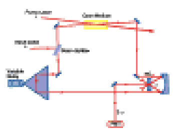


Torsion analogous to crystal dislocation

3. **Experimental test of electrodynamic torsion tensor theory.**
   If genuine, theory provides avenue to explore the possibility of creating asymmetric forces from an unverified coupling between mass, charge, and spacetime.
   Dr. Harry Ringermacher and Washington Univ, St. Louis, MO, NAS3-00094, Due Jan. 2001, R-2 / SM-3 -> SM-4.



4. **Exploration of anomalous gravity effect using superconductors.**
   If genuine, effect provides a tangible means to affect gravitational or inertial forces.
   Tony Robertson, NASA MSFC, Final report due 2001, R-2 / SM-1 -> SM-2.

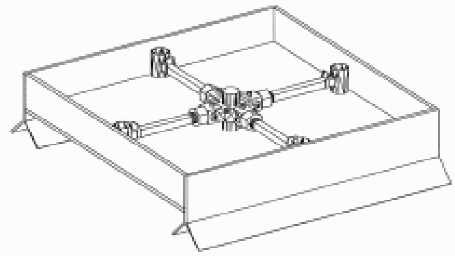


5. **Investigation of a superluminal hypothesis of quantum tunneling.**
   Addresses make-break issues of the light-speed limit (with commercial spin-offs).
   Dr. Kevin Malloy, Univ. NM, Albuquerque, NAS-300103, Final report due Feb. 2002, R-1 / SM-3 -> SM-4.

Supported Research Task # 1

Independent test of Woodward's transient inertia effect,

Dr. John Cramer, Univ. of Washington, Seattle WA



Critical Issue:

Is the transient inertia effect (utilizing a theoretical interpretation of Mach's Principle) as published by Woodward in 1991, a genuine physical effect?

BPP Relevance:

Directly relevant to a desired effect for BPP Goal 1 (Mass)

Example Founding references:

Woodward, J. F., *Foundations of Physics Letters* **4**:407-423 (1991)
Woodward, J. F., *Foundations of Physics Letters* **5**:425-442 (1992)
Woodward, J. F., *Foundations of Physics Letters* **9**:247-293 (1996)

Type of work:

Experimental test with theoretical assessment

Increment of Progress:

R-3 / SM-3 - to- R-3 / SM-4

Completion Due: February 2001

Supported Research Task # 2

Experimental and theoretical investigation of quantum vacuum energy,

Dr. J. Maclay, Quantum Fields LLC, WI, & MEMS Optical, Huntsville, AL.

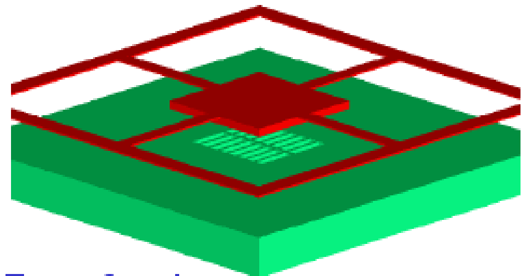
Critical Issue:
Existence of, magnitude of, and ability to interact with quantum vacuum energy.

BPP Relevance:
Critical make-break issues underlying desired effects for BPP Goals 1 (Mass) and 3 (Energy)

Example Founding references:

Casimir, "On the Attraction Between Perfectly Conducting Plates" Proc., Koninklijke Nederlandse Akademie van Westenshappen, Amsterdam, Vol. 51, pp. 793-796 (1948)

Forward, "Extracting Electrical Energy from the Vacuum by Cohesion of Charges Foliated Conductors" Physical Review B., B30, pp. 1770-1773 (1984)



Type of work:
Theoretical (QED) designs coupled to Experimental (MEMS) tests.

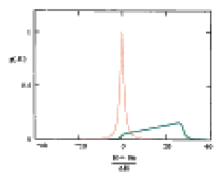
Increment of Progress:
R-2-3 / SM-3 - to- R-2-3 / SM-4

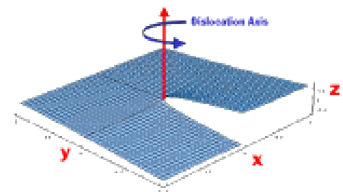
Completion Due: December 2002

Supported Research Task # 3

Experimental test of electrodynamic torsion tensor theory,

Dr. Ringermacher, Kronotran LLC, NY, & Washington Univ., St. Louis, MO





Torsion analogous to crystal dislocation

Critical Issue:
Test theory linking electromagnetism with spacetime which includes asymmetric components.

BPP Relevance:
Critical make-break issues underlying a desired effect for BPP Goal 1 (Mass)

Example Founding references:
Ringermacher, H. I., *Classical and Quantum Gravity* **11**:2383 (1994).

Schrödinger, *Space-Time Structure* (Cambridge Univ. Press, 1986).

Type of work:
Experimental (NMR) tests.

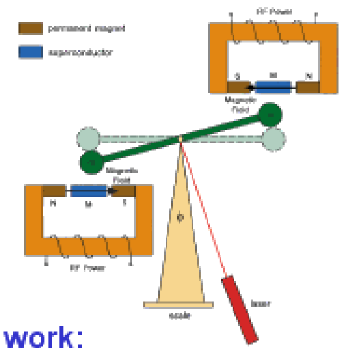
Increment of Progress:
R-2 / SM-3 - to- R-2 / SM-4

Completion Due: January 2001

Supported Research Task # 4

Experimental exploration of anomalous gravity effect using YBCO superconductors

Tony Robertson, NASA MSFC, Huntsville, AL



Critical Issue:
Explore the validity of unconfirmed observations and theoretical speculations of gravitational effects using YBCO superconductors & electromagnetism.

BPP Relevance:
Critical make-break issues underlying a desired effect for BPP Goal 1 (Mass)

Example Founding references:

- Podkletnov E. and Nieminen R., Physica **C 203** (1992) 441
- Li, N., et. al., Physica **C 281**: 260-267 (1997)
- Modanese G., Europhys. Lett. **35** (1996) 413 and Phys. Rev. D **54** (1996).
- Li, N., and Torr, Phys. Rev. **D, 43** (1990); and Phys. Rev. **B, 46** (1990).
- Torr, D.G. and Li, Found. Phys. Lett. **6** (1993) 371

Type of work:
Experimental (Cavendish bal.) tests.

Increment of Progress:
R-2 / SM-1 - to- R-2 / SM-2

Completion Due: February 2001

Supported Research Task # 5

Experimental and theoretical tests of superluminal hypothesis of quantum tunneling

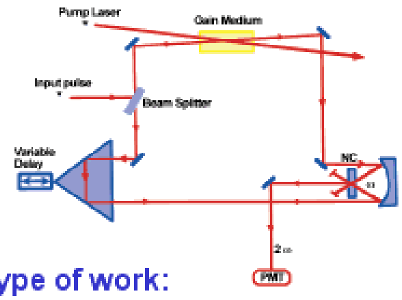
Dr. Kevin Malloy, Univ. of New Mexico, Albuquerque, NM.

Critical Issue:
Addresses the faster-than-light hypotheses of quantum tunneling, particularly in the case of amplification in the tunnel barrier.

BPP Relevance:
Underlying general physics related to a desired effect for BPP Goal 2 (Speed)

Example Founding references:

- Chiao, & Steinberg, "Tunneling times and superluminality ", in: Progress in Optics XXXVII, Oxford, Elsevier Sci. B. V. (1997), pp. 345-405
- Nimtz, G. and Heitmann, W., 'Superluminal Photonic Tunneling and Quantum Electronics ", Progr. In @ant. Electron. 2 1, 8 1- IOS (1997).
  - Numerous others



Type of work:
Experimental tests and theoretical assessments.

Increment of Progress:
R-1 / SM-3 - to- R-1 / SM-4

Completion Due: February 2002

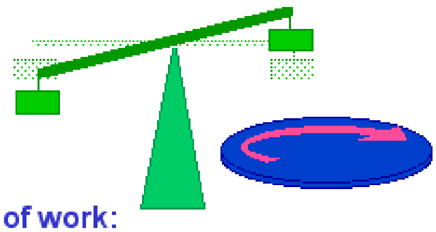
Parallel Research

Related NASA research not managed by the BPP Project

SBIR Phase 2 (MSFC)

Demonstrate the Feasibility of Fabricating a Dual Microstructure YBCO Toroid Suitable for Gravity Shielding Experiments

Superconductive Components Inc. Columbus, OH



Critical Issue:
Independent test of unconfirmed anomalous gravitational effects with YBCO superconductors.

BPP Relevance:
Critical make-break issues underlying a desired effect for BPP Goal 1 (Mass)

Example Founding references:
Podkletnov E. and Nieminen R., Physica **C 203** (1992) 441

Type of work:
Experimental tests.

Increment of Progress:
R-2 / SM-0 - to- R-2 / SM-2

Completion Due: 2001

John H. Glenn Research Center

Breakthrough Propulsion Physics Project

What Next?

Now revising project strategy to accommodate greater than anticipated number of approaches and interest.

Situation:

- Number of attractive 1st round NRA proposals exceeded expectations.
- More approaches have been received than can be assessed.
- Number of inquires about the project exceeds ability to respond.

Initial Response:

- No sequel research solicitation in FY2000.
- 1-year Hiatus from conference sessions.
- Considering publication to milestone the variety of approaches.
- Reassessing resource requirements.

Space Transportation Project Office

Marc G. Millis
27-Jun-00

John H. Glenn Research Center

Breakthrough Propulsion Physics Project

For More Information

Please visit the following web sites

BPP Project site:

Describes the methods and status of the BPP project:

http://www.grc.nasa.gov/WWW/bpp/

"Warp Drive - When?"

Oriented for public education about the difficulties and emerging possibilities for interstellar travel:

http://www.grc.nasa.gov/WWW/PAO/warp.htm

Mr. Millis regrets that he is not able to answer individual inquires at this time.

Space Transportation Project Office

Marc G. Millis
27-Jun-00

Back up charts follow

PPT Slide

Fundamental Limit of Rockets - PROPELLANT

(example: Propellant required to fly mass of Shuttle Orbiter past 4.3 Light-years)

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PPT Slide

WHEN is it time to seek the next breakthroughs?

Performance

Investment

When...

(1) existing methods are reaching their theoretical limits

and

(2) clues are emerging for new methods

(1)

(2)

New Clues

Fundamental Physics of Forces and Motion

Previous slide Next slide Back to first slide View graphic version

PPT Slide

Typical question from the public:

“This is not in the foreseeable future. Today it is still unknown if such visions are even achievable ...

but …

new possibilities continue to emerge from science.

NASA established the ‘Breakthrough Propulsion Physics Project ’ to pursue these possibilities.”

“When can we build something like this?”

Answer:

Next slide Back to first slide View graphic version

PPT Slide

Scientific Method (as readiness levels):

SM-4 Hypothesis empirically confirmed / dismissed

SM-3 Hypothesis proposed

SM-2 Data collected

SM-1 Problem formulated (identify relevant knowledge gaps)

SM-Ø Pre-science:

• Anomalous effect noted, or

• Correlation between goal & knowledge recognized.

Measuring Pre-Technology Progress

Relevance of science topic (as readiness levels):

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R-2 Critical make-break issue underlying the desired effect

R-1 Underlying general physics

First, specify the degree of relevance of the emerging science, and then specify the progress achieved within this relevance using the Scientific Method levels.

R-3/SM-4 = TRL-1

PPT Slide

< Knowledgeable conjecture: When you know

what you know, and know what you don’t.

(eg. Starship Enterprise)

< The very beginning: Visions without knowledge.

< Nature understood:

When you know what is “theoretically possible.”

(eg. Newton’s laws)

< Science applied: Devices engineered, built, tested.

(eg. space shuttle)

< Mature technology: Devices ready for common use. (eg. cars, aircraft)

Status of Potential Breakthrough Propulsion

(compared to a scale of technological advancement)

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PPT Slide

So what is NASA doing about it?

Scope of Effort

BPP Personnel: 1.14 person / year (i.e., Millis)

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Summed 1996 - 2000 and all tasks combined

(does not include salary of the 1.14 person)

All other support has been volunteered from scientists, engineers, and mangers across the USA and the world.

Some other parallel efforts also exist, but total $ unknown.

PPT Slide

Produce incremental, credible, and measurable progress toward conquering the ultimate breakthroughs needed to revolutionize space travel and enable interstellar voyages ...

Project Objective

… by advancing science to provide new foundations

for breakthrough technology.

PPT Slide

"… incremental, credible, and measurable progress …"

Sustain

Preeminence

Invest

Wisely

Vision

Prudence

Balancing Responsibilities

• Focus on immediate make-or-break issues.

• Sustain progress as a series of short-term, incremental tasks.

• Define "success" as acquiring credible knowledge rather than requiring a breakthrough.

• Explore multiple, divergent approaches simultaneously.

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PPT Slide

Vision with Credibility

• No jumping to conclusions; supportive nor dismissive

• Open minded to possible successes and impossibilities

• Converting objections into research objectives

- Entertain that it can be done

- Imagine the possibilities

- Draw on inspirations

- Pattern after past successes

- Be constructively skeptical

- Identify unsolved physics

- Build on known science

- Aim toward testable concepts

- use scientific method

Visionary

Credible

+

PPT Slide

"… the ultimate breakthroughs needed …"

1. Mass: Discover new propulsion methods that eliminate or dramatically reduce the need for propellant.

2. Speed: Discover how to circumvent existing limits to dramatically reduce transit times.

3. Energy: Discover new energy methods to power these propulsion devices.

These goals are THE breakthroughs needed to conquer the presently impossible ambition of human interstellar exploration.

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• Coupling of fundamental forces and spacetime (Gravity, Electromagnetism, etc).

• Space from the perspective of providing energy or reaction mass for space flight.

• Motion of matter and energy through spacetime.

• Interactions with spacetime (includes “warp drives,” “wormholes,” or other transport-related theories).

• Energy exchange mechanisms.

• Anomalous physical effects.

Physics of Interest

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(1) 1996

Define goals and determine if sufficient scientific foundations exist (YES).

(2) 1996

Network to identify possibilities and foster collaborations (Continuing).

(3) 1997

Determine if affordable candidate research tasks exist (YES).

(4) 1999-2000

Solicit , select, and support 1st round of research tasks (5 tasks so far).

(5) • 2001

Assess progress upon completion of 1st round of sponsored research (TBD).

Project Implementation

As a sequence of prudent, conditional steps

Now revising plans to accommodate greater than anticipated possibilities and interest.

PPT Slide

Networking Through Conferences and Workshops

• 1997 Kick-Off Assessment Workshop, 80 candidate tasks identified. (CP-1999-208694)

• 1998 STAIF 10 papers (AIP-420 pp.1435-1461, 1502-1534)

• 1998 Physics Lecture Series (MSFC & GRC-OAI)

• 1998 AIAA Joint Propulsion Conference 7 papers (AIAA 98-3136 … 98-3143)

• 1999 STAIF 23 papers (AIP-458 pp. 875-937, 954-1062)

• 1999 AIAA Joint Propulsion Conference, 5 papers (AIAA 99-2143 ... 99-2147)

• 2000 STAIF 19 papers (AIP-504 pp. 998-1132)

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• What's new? - reviewed emerging physics

- 14 established physicists gave overviews of recent scientific literature

- Pessimistic presentations included for balance

• Provoked thoughts using 30 Poster Papers

- Innovators with next-step ideas

- 1/3 Based on peer literature, 1/3 clearly “more adventurous” (too many)

• Produced a list of 80 candidate next-step research tasks

- Used facilitator-run breakout sessions

- Sought task ideas that focus emerging physics toward program goals

• 84 Participants

28 Industry, 16 University, 12 Students, 11 Other Government Labs, 17 NASA

1997 Kick-Off Workshop

To determine if affordable candidate research tasks exist

PPT Slide

Research Selection Criteria

* Mandatory Criteria

Technical Relevance:

A* Directness to program (must seek advances in physics that are relevant to propulsion or power).

B* Magnitude of potential gains for Goal #1 [Mass] + Goal #2 [Speed] + Goal #3 [Energy].

C Lineage (will it lead to further relevant advancements?)

D Status to be achieved upon completion of task (using scientific method levels as a metric)

(D-E)* Magnitude of progress to be gained by the work (using scientific method levels as a metric).

Probability of Success (credibility filters) :

F* Based on credible foundations (references must be cited)

G* Compared with current credible approaches (references must be cited)

H* Must be, or be leading toward, a credible discriminating test.

I* Probability of successful task completion (based on credentials and realism of proposal)

Note: Negative test results are considered progress

Programmatic Merit:

J Breadth of work (experiment, theory, and/or comparative study)

[Note: experiments are considered closer than theory to becoming technology, and are ranked higher]

K Triage (will it be done anyway or must this program support it?)

L Time required to complete task (reciprocal scoring factor)

M Funding required (reciprocal scoring factor)

PPT Slide

NRA Task Awards

1. Independent test of Woodward's transient inertia effect.

If genuine, this effect may enable thrusting directly against spacetime itself.

Dr. J. Cramer, U. of Washington, Seattle, C-78671-K, Final report due March 2001, R-3 / SM-3 -> SM-4.

2. Investigation of quantum vacuum energy.

Addresses make-break issues of vacuum energy: existence, magnitude, and transferability.

Dr. Jordan Maclay, Quantum Fields, WI, and MEMS Optical, Huntsville, AL,

NAS3-00093, Final report due Dec 2002, R-2-3 / SM-3 -> SM-4.

3. Experimental test of electrodynamic torsion tensor theory.

If genuine, theory provides avenue to explore the possibility of creating asymmetric forces from an unverified coupling between mass, charge, and spacetime.

Dr. Harry Ringermacher and Washington Univ, St. Louis, MO, NAS3-00094, Due Jan. 2001, R-2 / SM-3 -> SM-4.

4. Exploration of anomalous gravity effect using superconductors.

If genuine, effect provides a tangible means to affect gravitational or inertial forces.

Tony Robertson, NASA MSFC, Final report due 2001, R-2 / SM-1 -> SM-2.

5. Investigation of a superluminal hypothesis of quantum tunneling.

Addresses make-break issues of the light-speed limit (with commercial spin-offs).

Dr. Kevin Malloy, Univ. NM, Albuquerque, NAS-300103, Final report due Feb. 2002, R-1 / SM-3 -> SM-4.

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Supported Research Task # 1

Independent test of Woodward's transient inertia effect,

Dr. John Cramer, Univ. of Washington, Seattle WA

Critical Issue:

Is the transient inertia effect (utilizing a theoretical interpretation of Mach's Principle) as published by Woodward in 1991, a genuine physical effect?

BPP Relevance:

Directly relevant to a desired effect for

BPP Goal 1 (Mass)

Example Founding references:

Woodward, J. F., Foundations of Physics Letters, 4:407-423 (1991)

Woodward, J. F., Foundations of Physics Letters, 5:425-442 (1992)

Woodward, J. F., Foundations of Physics Letters, 9:247-293 (1996)

Type of work:

Experimental test with

theoretical assessment

Increment of Progress:

R-3 / SM-3 - to- R-3 / SM-4

Completion Due: February 2001

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Supported Research Task # 2

Experimental and theoretical investigation of

quantum vacuum energy,

Dr. J. Maclay, Quantum Fields LLC, WI, & MEMS Optical, Huntsville, AL.

Critical Issue:

Existence of, magnitude of, and ability to interact with quantum vacuum energy.

BPP Relevance:

Critical make-break issues underlying desired effects for BPP Goals 1 (Mass) and 3 (Energy)

Example Founding references:

Casimir, "On the Attraction Between Perfectly Conducting Plates" Proc., Koninklijke Nederlandse Akademie van Westenshappen, Amsterdam, Vol. 51, pp. 793-796 (1948)

Forward, "Extracting Electrical Energy from the Vacuum by Cohesion of Charges Foliated Conductors" Physical Review B., B30, pp. 1770-1773 (1984)

Type of work:

Theoretical (QED) designs coupled to Experimental (MEMS) tests.

Increment of Progress:

R-2-3 / SM-3 - to- R-2-3 / SM-4

Completion Due: December 2002

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Supported Research Task # 3

Experimental test of electrodynamic torsion tensor theory,

Dr. Ringermacher, Kronotran LLC, NY, & Washington Univ., St. Louis, MO

Critical Issue:

Test theory linking electromagnetism with spacetime which includes asymmetric components.

BPP Relevance:

Critical make-break issues underlying a desired effect for BPP Goal 1 (Mass)

Example Founding references:

Ringermacher, H. I., Classical and Quantum Gravity, 11:2383 (1994).

Schrödinger, Space-Time Structure, (Cambridge Univ. Press, 1986).

Type of work:

Experimental (NMR) tests.

Increment of Progress:

R-2 / SM-3 - to- R-2 / SM-4

Completion Due: January 2001

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Supported Research Task # 4

Experimental exploration of anomalous gravity effect

using YBCO superconductors

Tony Robertson, NASA MSFC, Huntsville, AL

Critical Issue:

Explore the validity of unconfirmed observations and theoretical speculations of gravitational effects using YBCO superconductors & electromagnetism.

BPP Relevance:

Critical make-break issues underlying a desired effect for BPP Goal 1 (Mass)

Example Founding references:

- Podkletnov E. and Nieminen R., Physica C 203 (1992) 441

- Li, N., et. al., Physica C 281: 260-267 (1997)

- Modanese G., Europhys. Lett. 35 (1996) 413 and Phys. Rev. D 54 (1996).

- Li, N., and Torr, Phys. Rev. D, 43 (1990); and Phys. Rev. B, 46 (1990).

- Torr, D.G. and Li, Found. Phys. Lett. 6 (1993) 371

Type of work:

Experimental (Cavendish bal.) tests.

Increment of Progress:

R-2 / SM-1 - to- R-2 / SM-2

Completion Due: February 2001

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Supported Research Task # 5

Experimental and theoretical tests of

superluminal hypothesis of quantum tunneling

Dr. Kevin Malloy, Univ. of New Mexico, Albuquerque, NM.

Critical Issue:

Addresses the faster-than-light hypotheses of quantum tunneling, particularly in the case of amplification in the tunnel barrier.

BPP Relevance:

Underlying general physics related to a desired effect for BPP Goal 2 (Speed)

Example Founding references:

• Chiao, & Steinberg, “Tunneling times and superluminality”, in: Progress

in Optics XXXVII, Oxford, Elsevier Sci. B. V. (1997), pp. 345-405

• Nimtz, G. and Heitmann, W., “Superluminal Photonic Tunneling and

Quantum Electronics”, Progr. In @ant. Electron. 21, 81- lOS(1997).

- Numerous others

Type of work:

Experimental tests and theoretical assessments.

Increment of Progress:

R-1 / SM-3 - to- R-1 / SM-4

Completion Due: February 2002

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SBIR Phase 2 (MSFC)

Demonstrate the Feasibility of Fabricating a Dual Microstructure YBCO Toroid Suitable for Gravity Shielding Experiments

Superconductive Components Inc. Columbus, OH

Parallel Research

Related NASA research not managed by the BPP Project

Critical Issue:

Independent test of unconfirmed anomalous gravitational effects with YBCO superconductors.

BPP Relevance:

Critical make-break issues underlying a desired effect for BPP Goal 1 (Mass)

Example Founding references:

Podkletnov E. and Nieminen R., Physica C 203 (1992) 441

Type of work:

Experimental tests.

Increment of Progress:

R-2 / SM-0 - to- R-2 / SM-2

Completion Due: 2001

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What Next?

Now revising project strategy to accommodate greater than anticipated number of approaches and interest.

Situation:

• Number of attractive 1st round NRA proposals exceeded expectations.

• More approaches have been received than can be assessed.

• Number of inquires about the project exceeds ability to respond.

Initial Response:

• No sequel research solicitation in FY2000.

• 1-year Hiatus from conference sessions.

• Considering publication to milestone the variety of approaches.

• Reassessing resource requirements.

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For More Information

Please visit the following web sites

Mr. Millis regrets that he is not able to answer individual inquires at this time.

“Warp Drive - When?”

Oriented for public education about the difficulties

and emerging possibilities for interstellar travel:

http://www.grc.nasa.gov/WWW/PAO/warp.htm

BPP Project site:

Describes the methods and status of the BPP project:

http://www.grc.nasa.gov/WWW/bpp/

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Back up charts follow

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Recognizing a Pattern from Historic Breakthroughs

(adapted from Foster, 1986)

To exceed the limits of existing methods, seek out entirely different methods.

Performance

Investment

Prior Methods

1- Sailing ships

2- Propellers

3- Aircraft

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NASA

Breakthrough Propulsion Physics

Project

- An Introduction -

Marc G Millis

Glenn Research Center, Cleveland Ohio

2000 - April

Contents:

• Lessons from prior breakthroughs

• Project approach and scope

• What's been done so far

• Currently supported research

• What's next ?

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1999-2000 Solicitation and Selection of Research Tasks

NRA-99-LeRC-1

General

• Total budget available for research tasks was $450K

• Opened November 1998, Selections June 1999, Awards January 2000.

NRA Focus

• Incremental tasks, just addressing next critical issue or curious effect

• Short-term (1-3 yr.) and low cost each ($50K - $150K)

• Open to credible, visionary concepts that have not yet been proven / disproven

• Explicit scoring criteria used to filter and rank proposals

Evaluation Process

• Stage-1 Review: > 51 peer reviewers scored proposals (min. 4 revr/ proposal)

• Stage-2 Review: 12 govt. reviewers compiled results and recommended selections

Selections

• 60 proposals received, 13 acceptable, funding available for top 5

• Different approaches selected - diversified portfolio

• Low level of effort each (spanned $37K - $171K)

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2001 JOINT PROPULSION CONFERENCE
BPP SESSION PAPERS

The following is a list of all papers presented at the BPP Session of the 2001 Joint Propulsion Conference. Some of this work was sponsored by the NASA BPP Project, some by British Aerospace Systems, some by private sources, and some were unsponsored. Papers from BPP-sponsored tasks are available by clicking on the corresponding links below. Copies of papers not sponsored by BPP are available, for a fee, through the AIAA (http://www.aiaa.org/). You may also consult your university library for availability. Listing of the non-BPP-sponsored papers does not necessarily imply any NASA endorsement of their contents.

Papers Sponsored by NASA's BPP Project:

AIAA-2001-3359

First Measurement of Repulsive Quantum Vacuum Forces
J. Maclay, Quantum Fields LLC, Richland Center, WI
J. Hammer, MEMS Optical Inc., Huntsville, AL
M. George and L. Sanderson, Univ. of Alabama in Huntsville, Huntsville AL
R. Clark, MEMS Optical Inc., Huntsville, AL

AIAA-2001-3364

Exploration of Anomalous Gravity Effects by rf-Pumped Magnetized High-T Superconducting Oxides
T. Robertson, NASA Marshall, Huntsville, AL

AIAA-2001-3906

Search for Effects of Electric Potentials on Charged Particle Clocks
H. Ringermacher, KRONOTRAN Enterprises LLC, Delanson, NY
M. Conradi and C. Browning, Washington Univ., St. Louis, MO
B. Cassenti, United Technologies Research Center, East Hartford, CT

AIAA-2001-3908

Tests of Mach's Principle with a Mechanical Oscillator
J. Cramer, Univ. of Washington, Seattle, WA

AIAA-2001-3909
Superluminal but Causal Wave Propagation
M. Mojahedi and K. Malloy, Univ. of New Mexico, Albuquerque, NM
R. Chiao, Univ. of California at Berkeley, Berkeley, CA

AIAA-2001-3657
Experimental Results of Schlicher's Thrusting Antenna
G. Fralick and J. Niedra, NASA Glenn Research Center, Cleveland, OH

Other Papers

These papers are listed to reflect activities related to BPP that sponsored by others. Listing of these papers here does not necessarily imply NASA endorsement of their contents.

AIAA-2001-3360
Geometrodynamics, Inertia, and the Quantum Vacuum
B. Haisch, California Inst. for Physics & Astrophysics, Palo Alto, CA

AIAA-2001-3361
Antimatter Production at a Potential Boundary
M. LaPointe, Ohio Aerospace Inst., Cleveland, OH

AIAA-2001-3363
Gravity Modification by High-Temperature Superconductors
C. Woods, Univ. of Sheffield, Sheffield, UK
S. Cooke, Cooke Computers, Jersey, British Isles

J. Helme, Univ. of Sheffield, Sheffield, UK
C. Caldwell, Motorola Ltd., Basingstoke, UK

AIAA-2001-3653
A Proposed Experimental Assessment of a Possible Propellantless Propulsion System
D. Goodwin, U.S. Department of Energy, Germantown, MD

AIAA-2001-3654 [Funded by a Congressional Earmark, and monitored by the BPP Project]
The Electromagnetic Stress-Tensor as a Possible Space Drive Propulsion Concept
J. Corum, T. Keech, S. Kapin, D. Gray, P. Pesavento, and M. Duncan, Inst. for Software Research, Fairmont, WV

AIAA-2001-3656
Research on Achieving Thrust by EM Inertia Manipulation
H. Brito, Instituto Universitario Aeronautico, Cordoba, Argentina

AIAA-2001-3658
Specially Conditioned EM Radiation Research with Transmitting Toroid Antennas
H. Froning Jr., Flight Unlimited, Flagstaff, AZ
G. Hathaway, Hathaway Consulting Services, Toronto, Ontario, Canada

AIAA-2001-3660
An Experimental Investigation of the Physical Effects in a Dynamic Magnetic System
V. Roschin and S. Godin, Russian Academy of Science, Moscow, Russia

AIAA-2001-3907
Rapid Spacetime Transport and Machian Mass Fluctuations: Theory and

Experiment
J. Woodward and T. Mahood, California State Univ., Fullerton, CA
P. March, Lockheed Martin Space Operations, Houston, TX

AIAA-2001-3910
Global Monopoles and the Bondi-Forward Mechanism
C. Van Den Broeck, Penn State Univ., Univ. Park, PA

AIAA-2001-3911
Induction and Amplification of Non-Newtonian Gravitational Fields
M. Tajmar, Austrian Research Centers Seibersdorf, Seibersdorf, Austria
C. de Matos, ESA-ESTEC, Noordwijk, The Netherlands

AIAA-2001-3912
Towards the Control of Matter with Gravity
D. Burton, C. Wang, T. Dereli, J. Gratus, W. Johnson, and R. Tucker,
Lancaster Univ., Lancaster, UK

AIAA-2001-3913
An Asymmetric Gravitational Wave Propulsion System
J. Cameron, Transdimensional Technologies, Inc., Huntsville, AL

-- last item --

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Millis, M. G. "**Illustrative Example: Destination Mars**", In Hazards to Spaceflight, International Space University Summer Program 1998, Sec. 2.3, pp. 15-19 (1998). Copies available through http://www.isunet.edu.

Web Version "Danger Mars," posted 2000/Aug/17

Preface:
In 1998, the summer session of the International Space University (ISU) conducted a study on the hazards to spaceflight. As a part of their final report, the following story was written to illustrate the very real hazards that exist in different regions of space and to illustrate the impacts that these hazards might have to future spacecraft, spacecraft crews, and life on Earth. Although the story is fiction, the hazards are real.

Danger Mars

Marc G. Millis

Day 0. Our mission begins ? the first human journey to Mars. Given recent advances in propulsion, our travel time to Mars will be shorter than the prior robotic missions, but it will still be a very long trip. Our transit time will be a little over nine months each way, and our stay on the surface will be even longer. In preparation for such a long duration mission, we have learned much from the research conducted aboard the Earth orbital stations. Also, the equipment that will support us on the Mars surface is already there and functioning. This is reassuring. Still, however, I know that this is a risky journey. In addition to the ever-present concern for equipment reliability, far away from any hope of repair, there are also hazards from the space environment. While in low Earth orbit we will be susceptible to orbital debris and meteoroids, and further out we will be vulnerable to meteoroids, solar radiation, and cosmic rays.

From our ground-based training I remember the first sobering lesson: this will be our only trip. During our long journey, each of us will receive enough exposure to the natural radiation in space that we can never fly again ? a "career-limiting dose," it is called. And this assumes only modest solar activity. If there is any unusually harsh solar activity during our mission, the dosage could be fatal.

Yes, this is a big risk, but it is also an epic adventure. We will be the first people visiting a totally new world. When I think about the covered wagons of the westward American expansion, where many lives were lost, the risks of this Mars venture seem minor compared to the potential gains. There are other people, however, who feel differently. The safety record of space activities has been so unusually good compared to other human activities, that accidents are not expected and not tolerated by the spectators. But those of us who have planned this voyage know the risks very well, and we accept them.

Day 1. We have just reached Earth orbit. The sensations of microgravity have begun to have their effects. Some of us felt nauseous. I don't think many would have welcomed the sight of food. After several hours, as we performed our post-launch checkouts, we all noticed that our upper bodies and faces were feeling fuller while our legs had become much slimmer - "swollen heads" and "chicken legs." The familiar faces of my crewmates became less familiar, plumped up by the redistribution of body fluids.

Day 2. We prepared for the transfer to our Mars Transit Cabin. By now, other microgravity effects have been felt: backaches from the change in loading on our spine and headaches from the redistribution of body fluids. I should note, however, that these unpleasant sensations are in stark contrast to the grandeur of the view - the Earth's glowing blueness just 400 km below. Also, we have all had fun floating about the cabin, performing gymnastic feats that are impossible on Earth. Just a few days more and we should all be adapted to microgravity. Then the unpleasantness will pass.

Day 4. We encountered our biggest problem to date. It appears that a small meteoroid or piece of space debris has struck one of the solar panels on the Mars Transit Cabin. Even though our staging orbit has been chosen by Space Traffic Control to minimize the chance of such collisions, collisions can still happen. Fortunately the damage is minor enough not to need any repair. Such impacts have been anticipated in the design of the spacecraft, and the appropriate margins have been built in to accommodate minor damage. To protect our cabin from small particles, Stuffed Whipple Shields surround our vehicle. Larger objects (bigger than about 1 cm), however, are still a problem. At the intersection velocities possible with criss-crossing orbits, a 1-cm particle would have the same kinetic energy as an automobile at about 60 km/h. Velocities of space debris in low Earth orbit can be about 15 km/s, a hundred times greater than a bullet. Even a particle as small as 1 mm can be dangerous. If a 1-mm particle hit a crewmember during EVA, for example, it would probably be fatal. Fortunately, the chances of such an EVA hit are slim (about one in 30,000).

Day 5. We settled into our Mars Transit Cabin, and began our transfer to the higher orbit where our Mars Transit Vehicle waits. The assigned trajectory was designed to avoid the orbits of existing satellites and the satellite "graveyard" above GEO, but now we faced another threat ? the radiation in the Van Allen belts. Although the Van Allen belts help protect the Earth from space radiation, this region itself is not a friendly environment. As we transferred through the Van Allen belts our craft was bathed in the high-energy particles oscillating in the belts. This radiation poses a hazard to the electronics aboard the spacecraft, causing "single event upsets" or "bit flips" that can disrupt their operation. In addition to the risk of high-energy protons damaging the electronics, this radiation can also cause portions of the spacecraft to charge up to high voltage. If the spacecraft had not been designed properly, this high voltage could suddenly discharge across the vehicle, causing serious damage to solar cells or other electronic components. Fortunately, the vehicle is equipped with surface conduction paths and plasma contactors to slowly discharge this voltage, and the electronic components have been designed to resist damage from sudden discharges.

Day 8. Now our vehicle has moved high enough that we are no longer within the protective shield of the Van Allen belts and the Earth's magnetosphere. The radiation in space that is normally blocked by the Earth's magnetic field is now impinging on our spacecraft. To some degree, the craft's structure can shield us from this radiation, but not completely. Although the average quantities of solar radiation are within tolerable limits, the real danger comes from spurious solar flares and coronal mass ejections that could cause dangerously high levels of radiation. Our craft is equipped with x-ray detectors that will give us several minutes of warning should such events occur, since x-rays travel faster than the more dangerous high-energy particles. In the case of an x-ray alarm, we have time to move to the "shelter" - the best-shielded portion of our Mars Transit Cabin. Solar radiation is not the only source of radiation, however. In addition, high-energy cosmic rays pose some risk. Due to compromises between shielding mass, trip duration, and "acceptable" risk, the ship has only a certain amount of shielding. This is due to mass limitations and the fact that some types of radiation simply cannot be blocked. Also, the ship's materials have been chosen to minimize secondary radiation. Secondary radiation is the radiation created by the impact of high-energy particles on the materials in the ship, where other forms of radiation are created, which can then impact us.

Day 13. A few days ago we reached the Lunar Staging Area. The docking of our Mars Transit Cabin with the Mars Transit Vehicle went flawlessly. We have checked out all of the systems of our combined vehicle and feel confident that it is fully functional. We are ready to begin our journey to Mars.

Day 68. We have been en-route to Mars for a couple of months now. As I was exercising this morning, I noted a strange smell. I find exercising a boring, yet necessary, task to keep up my health in microgravity, and I was initially glad to be diverted. Investigating, I found a swath of a dark furry growth on the inside of one of the panels next to the air handling equipment. Such "unwanted growth" poses a pathogenic health hazard. As it turns out, bacteria thrive in microgravity, and to compound this issue, the human immune system seems to weaken. I covered my nose and mouth with a filter screen, got out the cleansing kit, and cleaned the panel. The rest of the crew then checked the other locations as well. It's too bad the growth we scraped off wasn’t edible. The monotony of the diet is beginning to take its toll. Until now I never realized how much mental comfort I derived from simply eating a variety of tasty foods. Right now I'd feel better if I could just remember the taste of chocolate.

Finding this growth reminds me of a similar concern. Just as bacteria can thrive in microgravity, they can also mutate. Research on Earth orbital stations found that microorganisms are more prone to mutate in space than on Earth. This not only poses a pathogenic risk, but also a risk to "good" bacteria. In our Biowaste Recycling System, for example, bacteria play a crucial role in breaking down our feces. If these bacteria were to mutate, they might lose their ability to perform this necessary function and thus endanger this part of our life support equipment. We are somewhat prepared for this contingency. On board we have back-up cultures of this bacteria that we can reintroduce into our Biowaste Recycling System. I dearly hope that this doesn’t happen, however. "Rebooting" our Biowaste system is not a pleasant job.

Day 125. After four months en-route, we have faced our first real emergency: we had to perform an operation in space. Our geologist had contracted kidney stones, presumably formed from the calcium that leaches out of the bones in microgravity. Kidney stones are one of the anticipated medical problems for such long duration flights and thus we are equipped to deal with it. What surprised us was how quickly this problem arose and that the medication prescribed to the geologist had not worked. The pain had become severe enough that he asked our doctor to operate. The operation went well, and he is recovering nicely. He even appreciated our joke about him trying to collect rock samples (stones) too early in the mission.

Day 197. We've now been en-route for six months. According to the mission doctor, I am in good physical condition, well, as good as can be expected in microgravity. My state of mind, however, is certainly strained. Even our good doctor, who is also trained as a psychiatrist, is getting quite irritable. She really did not take well to my "doctor heal thyself" comment today.

We knew from our training that cramped conditions with the same faces day-in and day-out would wear on our nerves. Somehow it seems worse now than it did in the ground simulations back on Earth. Maybe it is the fact that we now experience difficulties communicating with Earth, an unexpected circumstance. While we've been en-route to Mars, there was an accident in Earth orbit. Some fragment of Earth-orbiting debris collided with a satellite, resulting in more debris, damaging several other satellites. This cascading destruction took out communication satellites of several constellations, including those used for our mission operations. Apparently this accident affected far more than just our mere Mars mission. These satellites were also used for business and financial communication, mobile phones, and even TV and Internet broadcasts. The economic impact of such major communication failures is still being assessed. Many business and financial transactions were interrupted during the incident, causing huge amounts of "virtual" money to be misplaced. The disruption in phone service touched the lives of a large segment of the Earth population. And the broadcasts of the World Cup games were cut off, triggering riots in some areas.

The worst of it, however, is that this incident has heightened military tensions in volatile parts of the globe. One of the damaged satellites was from a "developing" nation, and they are blaming the accident on debris from the "developed" nations. Since only developed nations have the ability to monitor space debris, the developing nation is accusing them of withholding data on the incident and even suggesting that it was deliberate. Although these events have me concerned, I must instead concentrate on life aboard our own little Mars Transit Cabin.

Day 254. We are getting closer to Mars and the crew is finding new energy from their enthusiasm. We have ramped up our physical conditioning so that we will be able to work when we get on the surface. Even though Mars has only 38% of the Earth's gravity, it is expected that it will take us at least one full day to become accustomed to having weight again. Without the preconditioning it would take even longer. To motivate ourselves, we have made a competition on board. We are ignoring the carefully negotiated mission plan for who will be the first to step onto the Martian soil. We've agreed that the first one of us who can actually get up and walk around the cabin for 15 minutes will be the one who steps out on the surface first. I'm not sure yet whether this deal is helping, or further straining, crew tensions. I am glad that we are, at least, still talking to each other - well, some of the time.

Day 262. The x-ray detector sounded an alarm - another solar event. This was the third radiation alert during our mission. We followed procedure and got into the best-shielded area of our craft. Sitting in the shelter, I missed the "spaciousness" of our normal cramped quarters. Several minutes later, I began experiencing one of the signs that the radiation had arrived: I saw flashes of light. The flashes were not in the cabin; they were inside my own eyes. It is thought that this phenomenon is caused by the high-energy particles striking the retina, sending false signals to the brain that light-flashes occurred. The Apollo astronauts in transit to the Moon and even the Mir astronauts noticed this, particularly when Mir passed through the "South Atlantic Anomaly."

Silently we watched the dosimeter readings, knowing that the shielding could not protect us from all of the radiation. The readings began to rise. One of us asked the doctor when we would exceed our "career-limiting dose". She paused and opened her palmtop, checking for the information. She has been keeping track of the past events, keeping a running total of the accumulating dosages. She had also put us on a medical regime after the first solar storm to minimize the detrimental effects. The radiation had also affected her computer. As she persisted at her task, the dosimeter continued to rise.

After 70 minutes the storm had passed. The doctor sighed and passed around her palmtop for all of us to read. Total accumulated dose: 680 rem. I think to myself that it must have been an anomalous solar flare, one that coincidentally lined up with our path. Although the mission was conducted during a time of solar minimum, solar activity can still surprise us. It did today. Nothing was said. We left the shelter; several of us already showing some symptoms. Most of us went quietly to communication stations. We sent the news, and our good byes, to home. I regret that we will never make it to Mars. I would have much preferred to meet my end there instead.

End of Story

[Return to BPP Project home]

Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004

Millis, "**Social Impact of Access to Space**," in *Aerospace Frontiers* (the internal news publication of NASA Glenn Research Center), Vol. 2, Issue 8 (August 2000).
Web Version posted 2000/Aug/17

Preface:
The internal news publication of NASA Glenn Research Center ("Aerospace Frontiers") is running a series of fictional stories from employees and retirees of Glenn and its affiliates about visions of the future. This fictional story, by Marc Millis, is the third in the series.

Social Impact of Access to Space

Marc G. Millis
2000-July-10

From the Author: The visions presented here do not necessarily reflect the opinions of NASA, Glenn, "Aerospace Frontiers," or even the author himself. What this story does represent, however, is a light-hearted glimpse of an unintended turn of events. History itself is a collection of unplanned twists and turns, so our visions of the future should prepare us for more of the same. Prepare yourself.

It finally happened. Access to space became cheap enough so that the average "Joe" and "Joanne" could venture beyond the bounds of Earth, and long-duration space habitats became robust enough to provide reliable places to live once they got up there. We truly became a "spacefaring" civilization. The face of humanity changed.

It didn't quite evolve as expected. Sure, we finally made that grand observatory and hotel on the Moon, had a multinational colonization of Mars that made the International Space Station pale in comparison, and even sent out interstellar probes. But after the novelty of Moon vacations and zero-g sex wore off (space sickness really put a damper on those romantic weekend getaways), the humanism of space took on a more *human* course of events.

As it turned out, it wasn’t the average Joes and Joannes who went out in search of adventure. Instead, it started with hordes of self-proclaimed misfits that finally escaped the bounds of Earth -- specifically escaping the oppression of the authority figures that had the audacity to expect them to obey laws and social norms. Individuals and clusters of subcultures set up residency in space to create their own little worlds on whatever piece on non-Earth territory they could find. Asteroids became the favorite homesteading choice for these escapists. Mars and the Moon had too much of that old Earth-culture to be attractive. Religious cults, hate-mongers, and ultra-geeks each claimed their piece of a rock. In isolation, their cultural diversity blossomed.

Enter stage two. Medical needs and simple cravings drove these escapists to invite the mainstream humans out to service them. Roving med-service and fast food space ships made weekly runs across the asteroid belt. And this created another shift. Although space habitats were built to be self-sufficient (which meant they didn’t need further investment once purchased) junk food and medical help cost money. Now the escapists needed jobs. Some, like the ultra-geeks, had no trouble pulling in finances over the Internet with their intellectual services, but other groups turned to some of the oldest professions including, among other things, piracy.

Space Pirates evoked the need for space patrols. This meant that those old authority figures were back again, but now they were the outsiders. Skirmishes broke out like dogs barking at night. And it wasn’t just the escapists versus the conventionalists. The inherent diversity of the various escapists combined with their human instincts for territorialism, led to battles amongst the groups. With zeal akin to religious righteousness, the cries went out: "My way is the right way ? convert or die!"

Meanwhile, as these "cultural exchanges" ran their course, another technology infusion made a dramatic impact. Drawing on genetic engineering and biomechanical technology, it became chic to "reinvent yourself." The ultra-geeks now had the resources and will to modify their own bodies to be better suited to their new space environment: rad hard, micro-g adapted, power boosted, and so forth. Some even went as far as to mutate themselves into having insect-like exoskeletons to endure the space vacuum, complete with eyes in the back of their heads and appendages armed with automatic targeting weapons. Even though life on Earth remained pretty much the same, this engineered biodiversity flourished in space beyond terrestrial imagination.

Survival of the fittest eventually ran its course. What remained to dominate the space frontier no longer looked quite human, but still retained all the instincts for territorial and conquest of their human origins. The ***face*** of humanity had literally changed.

(Artwork by Millis, ©1998)

End

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Responsible Official for Content: Marc G. Millis
Curator: -- Not presently available --
Last update: May 13, 2004

Marc G. Millis
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Responsible Official for Content: Marc G. Millis
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Last update: May 13, 2004

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FEATURE

Warp Drive, When?

Have you ever wondered . . .
When can we build something like the futuristic spacecraft shown above?

Have you ever wondered when we will be able to travel to distant stars as easily as in science fiction stories? NASA Glenn's Marc Millis (pictured above), who has taken a break from Project Management for NASA's Breakthrough Propulsion Physics (BPP) Project to return to conducting research, offers this assessment of the prospects for achieving the propulsion breakthroughs that would enable such far-future visions of interstellar travel.

This web site focuses on the propulsion related issues, explaining the challenges of interstellar travel, existing propulsion ideas, and the possibilities emerging from scientific literature that may one day provide the desired breakthroughs. To simplify the presentation for the general public, analogies to familiar science fiction are used. This site is intended for public audiences, whereas researchers might want to check out the Breakthrough Propulsion Physics Project web site.

Contents

Why is interstellar travel so tough?

Before we begin to look the answers, we need to define the problem. Let's start by looking at just how big the challenge is and the radical breakthroughs that will be required.

From Inspirations to Inventions

Some ideas for interstellar travel have been proposed. Let's examine them and the status of some of the technologies.

Ideas based on what we know

A brief description of some ideas that have been suggested over the years for interstellar travel, ideas based on the sciences that **DO** exist today.

Ideas based on what we'd like to achieve

A brief description of some ideas that have been suggested more recently which will require major breakthroughs.

Some Emerging Possibilities

Some more advanced concepts based on emerging physics.

Links to Related NASA Activities

A variety of links to official NASA activities with implications for interstellar space travel.

So, can we do it?

Resources

Frequently Asked Questions

Answers to a few of questions that you are likely to have.

"Science fiction or fact?" - An MSNBC Survey

So what do you think about interstellar travel?

Lewis News Article

A general discussion of the issues and concepts as printed in Glenn's (formerly Lewis) internal newsletter.

Detailed Narrative

The requirements for and an explanation of the emerging physics associated with intersellar travel.

Annotated Bibliography

A list of relevant books, articles, etc. with Marc's notes and comments.

In October 1995, Telarc International sampled sounds at 14 locations across NASA Glenn that served as the raw material to create "Symphonic Star Trek" -- a collection of the series' most memorable music and sound effects.

Hear some of the sounds!

Editor: Kathleen Zona
NASA Official: Brian Dunbar
Last Updated: July 1, 2005
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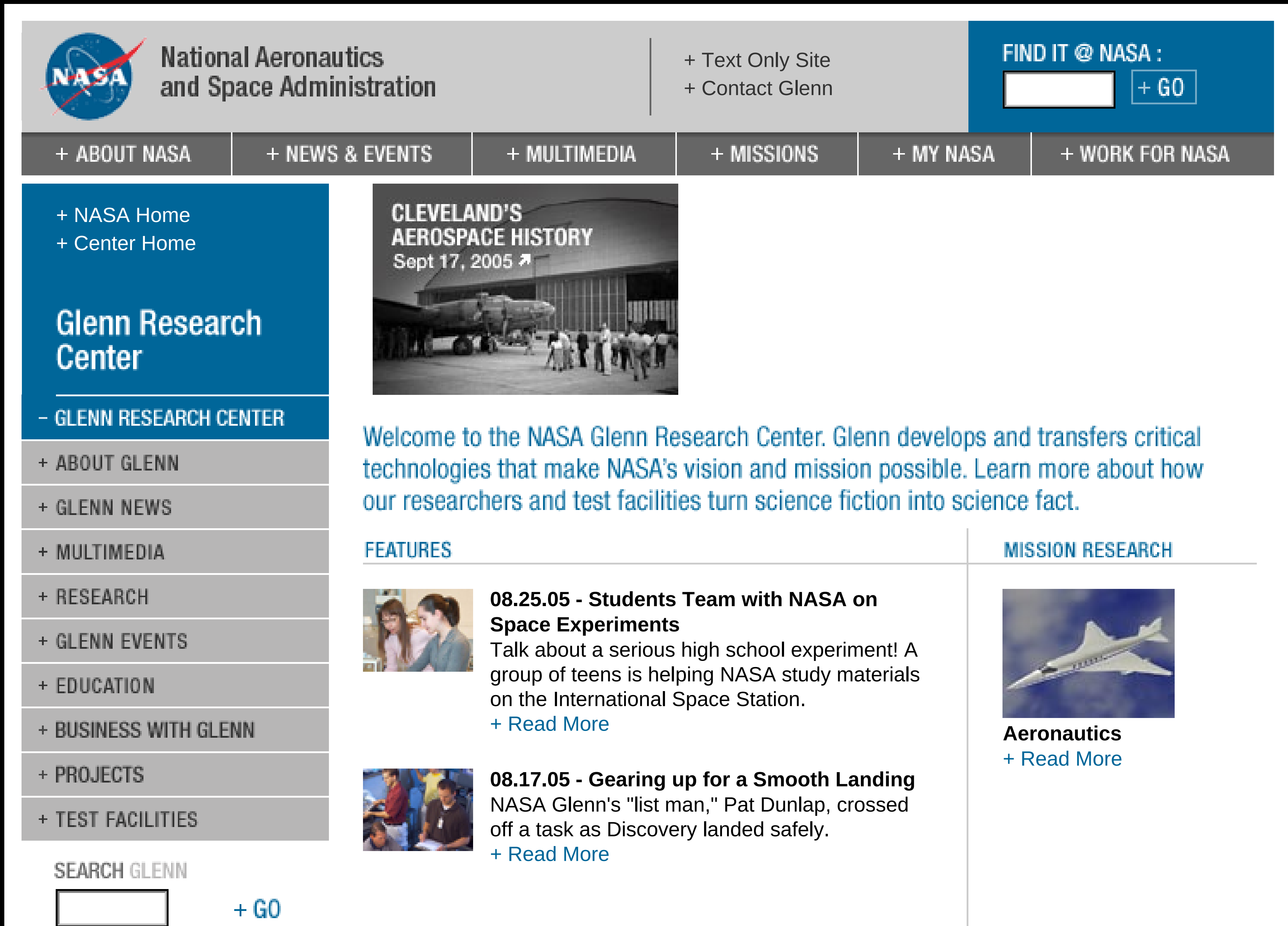
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Alan Shepard is the only person to hit a golf ball on the Moon. During the Apollo 14 mission he fitted an 8 iron head to the handle of a lunar sample collection device and launched three golf balls. They are still there!

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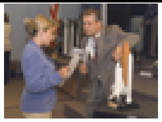

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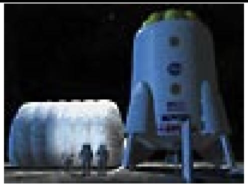

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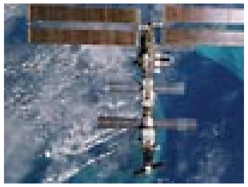

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08.05.05 - Public Invited to View Shuttle Landing at Glenn's Visitor Center
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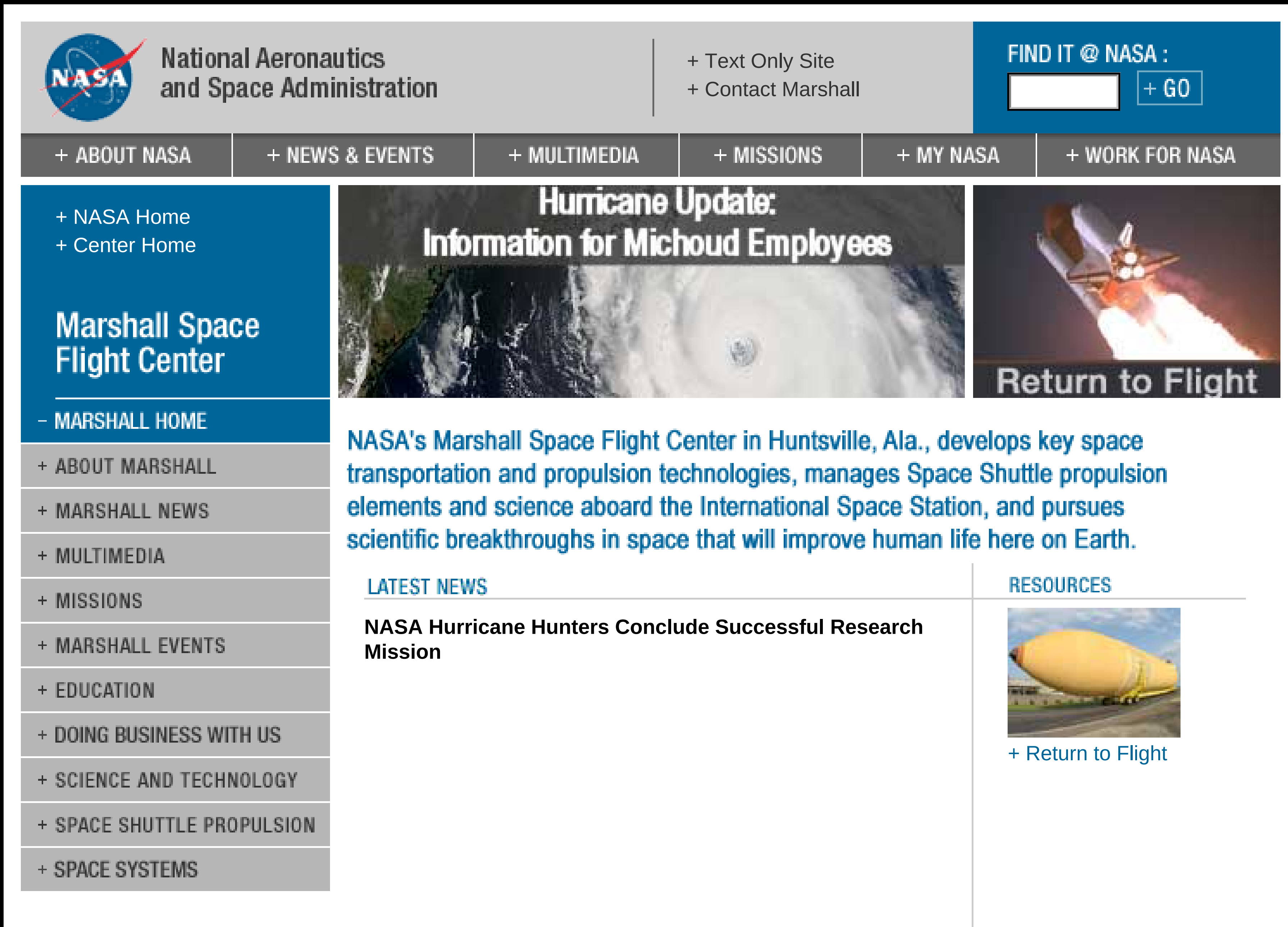
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NASA's Marshall Space Flight Center in Huntsville, Ala., develops key space transportation and propulsion technologies, manages Space Shuttle propulsion elements and science aboard the International Space Station, and pursues scientific breakthroughs in space that will improve human life here on Earth.
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NASA Hurricane Hunters Conclude Successful Research Mission
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NASA and Marshall Center scientists and their colleagues have concluded a month-long research mission in Costa Rica, recording unprecedented data about the birth and evolution of hurricanes and other tropical storms. Such research could improve forecasting capabilities to better safeguard lives and property against killer storms like Hurricane Katrina.

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Marshall Center Astronomers Have Asteroids Bearing Their Names

Marshall Center astronomers Dr. Bill Cooke and Dr. Rob Suggs have learned that two asteroids -- orbiting the Sun nearly 300 million miles away between Mars and Jupiter -- now bear their names. The team that discovered the asteroids was familiar with the work of Cooke and Suggs for NASA in the field of meteor showers.

+ News Release
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See Earth From Mercury-Bound Spacecraft

On a recent swing by Earth, the Mercury-bound MESSENGER spacecraft captured several hundred stunning images of its home planet. A movie created from those images follows Earth through one complete rotation, with the movie’s final frame taken from 270,847 miles away -- farther than the Moon’s orbit. MESSENGER, short for MErcury Surface, Space ENvironment, GEochemistry and Ranging, is the seventh mission in NASA's Discovery Program of lower cost, scientifically focused exploration projects.

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Unique NSSTC Lab Tackles 'Sticky' Issue of Lunar Dust

Inside a laboratory at the National Space Science and Technology Center (NSSTC) in Huntsville, Marshall Center researchers are isolating and studying individual grains of dust. But this dust comes from the Moon -- and could play a vital role in helping American explorers safely return there in coming decades.

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Chandra Observatory Marks Six Years

In August 1999, NASA's Chandra X-ray Observatory opened for business. Six years later, it continues to achieve scientific firsts. During the observatory's sixth year of operation, auroras from Jupiter, X-rays from Saturn, and the early days of our solar system were the focus of Chandra discoveries close to home.

Image above: Artist concept of NASA's Chandra X-ray Observatory
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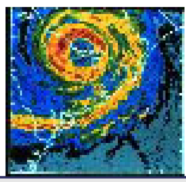

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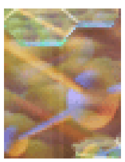

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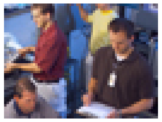

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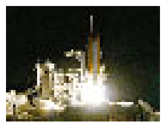

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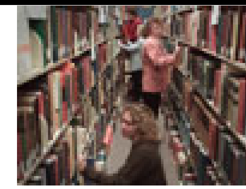

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DEEP SPACE MISSIONS

NASA Glenn Deep Space-1:
NASA Glenn Provided Critical Technologies for Deep Space 1 Mission

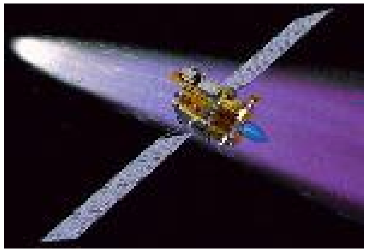


Image left: DS1 Spacecraft Illustration. Credit: NASA

Deep Space 1 (DS1), the first of NASA's New Millennium Program missions, tested 12 advanced technologies and instruments in space during a highly successful mission that ended on Tuesday, December 18. DS1's flight testing of new technologies pioneered the way for future spacecraft and missions to have an arsenal of revolutionary technical capabilities for exploring the universe. The NASA Glenn Research Center, which pioneered solar electric propulsion, played a key role in the development of DS1's Ion Propulsion System (IPS) and Solar Concentrator Arrays (SCA) that were demonstrated on this trailblazing mission. The NASA Glenn technologies performed well, exceeding all of their technology validation success criteria. The relatively small spacecraft, reaching just 8.2 feet (2.5 meters) in height, was launched aboard a Delta II rocket from Cape Canaveral Air Station, FL on October 24, 1998.

DS1 traveled along a "test track" that took it near asteroid Braille in July 1999 and on a risky, but successful, encounter of the comet Borrelly on September 22, 2001. The ion propulsion system enabled the spacecraft to close in on the comet Borrelly at a rate of 750,000 miles per day. Deep Space 1's risky encounter with comet Borrelly went extremely well as the spacecraft passed within about 1,400 miles (2,200 kilometers) of the comet. Although the primary mission for DS1 officially ended on September 18, 1999, NASA management extended the mission to cover the Borrelly encounter.

NASA sent the final commands to its Deep Space 1 spacecraft on Tuesday, December 18, 2001. The ion engine which provided primary propulsion, and eventually 2-axis attitude control,

+ GO

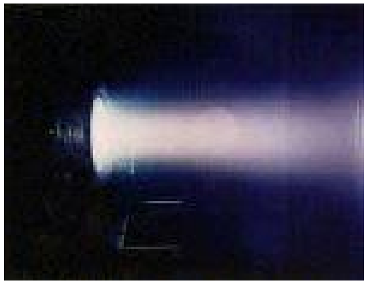
operated for 16,246 hours and has consumed about 72 kilograms of xenon propellant. After Earth's final goodbye, the spacecraft remains in orbit around the Sun, operating on its own. Its radio receiver will be left turned on, in case future generations want to contact the spacecraft.

/ Ion Propulsion System / Power System / Ion Propulsion History / "Distant" Future Propulsion /

Beyond Chemical Propulsion

Glenn Ion Thruster Propelled Deep Space 1

Image right: Ion Engine firing. Credit: NASA.



One revolutionary technology was the Solar Electric Propulsion (also known as Ion Propulsion) system developed and managed by Glenn's On-Board Propulsion Branch. Ion propulsion, once only a futuristic technology that for decades catapulted spacecraft through the pages of science fiction novels and movies, uses electrically charged gas as the propellant instead of chemicals like liquid hydrogen and oxygen.

Solar electric propulsion (SEP) offers significant mass savings for future deep-space and Earth-orbiting missions with high delta V requirements. The technology is so efficient that it only consumes about 3.5 ounces (100 g) of Xenon per day, taking about four days to expend just one pound (0.4 kg).

The objective of the **NSTAR** (NASA SEP Technology Application Readiness) program was to validate low-power ion propulsion, which fits well with the New Millennium Program's goals. The joint Glenn Research Center/Jet Propulsion Laboratory effort, which was started in November 1992, has been building and ground testing ion propulsion hardware in parallel with fabricating flight hardware for Deep Space 1.

The ion propulsion system on NASA's Deep Space 1 spacecraft came to life Tuesday, November 24, 1998 and maintained its operations throughout the mission. During its acceptance test, the ion engine ran more than twice as long as it was originally planned to thrust without interruption at any time during the mission. By running the ion engine for more than 200 hours and successfully conducting technology validation of the spacecraft's solar array and transponder (radio transmitter/receiver), the team achieved the minimum criteria that NASA established for overall mission success. In mid-August of 2000, the Deep Space 1 Probe set a record for engine operations. The spacecraft had run its unique propulsion system for more than 200 days (4800 hours). That surpassed the previous record for ion propulsion systems set by the NASA Space Electric Rocket Test 2 that thrusted for about 161 days.

Please refer to the Operation Sequence and Status page for the complete account of the NSTAR Ion Propulsion System.

Related information:

- ***Innovative Engines: Glenn Ion Propulsion Research Tames the Challenges of 21st Century Space Travel*** [HTML] [PDF]
- Glenn Chosen to Lead Development of NEXT Ion Engine (Press Release 02-046, 7-1-02)
- NASA BIDS FAREWELL TO THE SUCCESSFUL DEEP SPACE 1 MISSION (HQ Press Release 01-246, 12-17-01)
- AGING NASA SPACECRAFT CAPTURES BEST-EVER VIEW OF COMET'S CORE (HQ Press Release 01-186, 9-25-01)
- DEEP SPACE 1 SPACECRAFT KEEPS GOING . . . AND GOING . . . (HQ Press Release 00-125, 8-15-00)
- ION PROPULSION SYSTEM WINS DISCOVER MAGAZINE AWARD (Press Release 99-51, 6-22-99)
- EXOTIC TECHNOLOGIES FINISH ROAD TEST ON COSMIC HIGHWAY (HQ Press Release 99-49, 4-6-99)
- ION PROPULSION SYSTEM ON DEEP SPACE 1 RUNNING SMOOTHLY (Press Release 98-60, 12-8-98)
- How the Ion Engine Works
- Ion Propulsion Overview

Harnessing Helios

Glenn Solar Array Technology Powered Deep Space 1

Image left: SCARLET deployed. Credit: NASA.

Because of the ion engine's power requirements, Deep Space 1 required high-power solar arrays. NASA Glenn's Photovoltaic Branch and Space Environment Effects Branch worked as part of the design team to meet this need by combining high-performance solar cells with lenses designed to focus sunlight on them. The decision was to employ Glenn's Solar Concentrator Arrays with Refractive Linear Element Technology (SCARLET) design concept. An earlier version the solar array was included as a test on a satellite on the unsuccessful launch of the Conestoga launch vehicle in October 1995, so it was never tested in space.

Concentrator arrays offer a number of generic benefits for space, while the line-focus concentrator concept offers very important advantages. New array designs emphasize light weight, high stiffness, stowability, and ease of manufacturing and assembly. The concept was modified for the two SCARLET II arrays for DS1. Within the first two hours after launch, the two arrays were deployed and their operation was validated. In the process of taking the ion propulsion system to high throttle levels during the first full week of thruster operation, the mission team gathered additional validation data on the solar arrays. This was the first opportunity that the arrays had to provide high power, because the propulsion system has the greatest power requirements of any unit on board.

The spacecraft is equipped with two solar wings, each of which is composed of four panels measuring about 44 by 63 inches (113 by 160 centimeters). At launch, the wings were folded up so that the spacecraft would fit into the launch vehicle's fairing; now fully extended, the wings measure 38.6 feet (11.8 meters) from tip to tip. A total of 720 cylindrical Fresnel lenses made of silicone concentrate sunlight onto 3,600 solar cells made of a combination of gallium indium phosphide, gallium arsenide and germanium.

The arrays produce 15 to 20 percent more power than most modern solar arrays of the same size - about 2.4 kilowatts (kW) at the beginning of the mission (declining over the life of the mission as the array ages and the spacecraft recedes from the Sun) with a voltage of 100 volts.

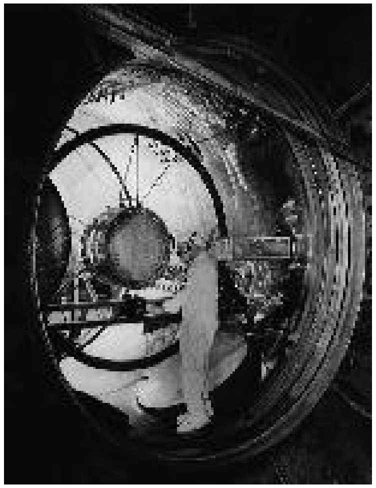
An operational assessment was done on November 30, 1998 to determine that the peak power point for the solar concentrator arrays is approximately 2.15 kW.

Researchers at NASA Glenn, worked in collaboration with the Ballistic Missile Defense Organization and, AEC-Able Engineering Inc. and Entech, Inc., one of NASA Glenn's successful Small Business Innovation Research (SBIR contractors.

Pioneering Research

Early Work at NASA Glenn Turned Sci-Fi into Reality

Image right: Ion Engine firing. Credit: NASA.



Ion propulsion - also known as solar-electric propulsion because of its dependence on electricity from solar panels - has been under development since the 1950s. Dr. Harold Kaufman, an engineer at NASA Glenn (since retired), built the first ion engine in 1959. In the 1960s, NASA Glenn undertook a spaceflight test program called, Space Electric Rocket Test (SERT).

In 1964, a pair of NASA Glenn ion engines were launched on a Scout rocket from Wallops Island, VA, under the name SERT 1, one of the two thrusters onboard did not work, but the other operated for 31 minutes. NASA Glenn also lead the way for a follow-up mission, SERT 2, which carried two ion thrusters, one operating for more than five months and the other for nearly three months.

Many early ion engines used mercury or cesium instead of xenon. SERT 1 carried one mercury and one cesium engine, while SERT 2 had two mercury engines. Apart from the fuel, these ion drives were similar to Deep Space 1's; the mercury or cesium would be turned into a gas, bombarded with electrons to ionize it, then electrostatically accelerated out the rear of the engine. But mercury and cesium proved to be difficult to work with. At room temperature, mercury is a liquid and cesium is a solid; both must be heated to turn them into gases. After exiting the ion engine, many mercury or cesium atoms would cool and condense on the exterior of the spacecraft. Eventually researchers turned to xenon as a cleaner and simpler fuel for ion engines.

Beginning in the 1960s, the Hughes Research Laboratories, Malibu, CA, conducted development work on ion engines. The first xenon ion drive ever flown was a Hughes engine launched in 1979 on the Air Force Geophysics Laboratory's Spacecraft Charging at High Altitude (SCATHA) satellite. In August 1997, Hughes launched the first commercial use of a xenon ion engine on PanAmSat 5 (PAS-5), a communications satellite launched on a Russian Proton rocket from the Baikonur Cosmodrome in Kazakhstan. This ion engine is used to maintain the position of the communications satellite in its proper orbit and orientation. Ion engines for such purposes are smaller than systems like Deep Space 1's, which is designed for long- term interplanetary thrusting.

Image left: NSTAR ion engine. Credit: NASA.

In the early 1990s, JPL and NASA Glenn partnered on an effort called the NASA Solar Electric Power Technology Application Readiness (NSTAR) project. The purpose of NSTAR was to develop xenon ion engines for deep space missions. In June 1996, a prototype engine built by NASA Glenn began a long-duration test in a vacuum chamber at JPL simulating the conditions of outer space. The test concluded in September 1997 after the engine successfully logged more than 8,000 hours of operation.

Results of the NSTAR tests were used to define the design of flight hardware that was built for Deep Space 1 by Hughes Electron Dynamics Division, Torrance, CA, and Spectrum Astro Inc., Gilbert, AZ. Other partners in the development of the Deep Space 1 flight engine included Moog Inc., East Aurora, NY, and Physical Science Inc., Andover, MA. Development of the xenon ion propulsion system was supported by NASA's Office of Space Science and Office of Aeronautics and Space Transportation Technology, Washington, DC. A portion of the NSTAR program was supported by the Advanced Space Transportation Program, managed by NASA's Marshall Space Flight Center, Huntsville, AL.

Related information:

- A Synopsis of Ion Propulsion Development Projects in the United States: SERT I to Deep Space I (NASA/TM-1999-209439) [245 Kb PDF]
- The History of Ion Propulsion (A more extensive look into Ion propulsion)
- NASA Glenn History

Pioneering The Future

On-going Work at Glenn Looks at Breakthrough Propulsion Concepts

Image left: Interstellar concept. Creidt: NASA.

NASA is embarking on a new, small program called Breakthrough Propulsion Physics to seek the ultimate breakthroughs in space transportation: (1) Propelling a vehicle without propellant mass, (2) attaining the maximum transit speeds physically possible, and (3) creating new energy production methods to power such devices. Because such goals are beyond the accumulated scientific knowledge to date, further advances in science are sought, specifically advances that focus on propulsion issues. Because such goals are presumably far from fruition, a special emphasis of this program is to demonstrate that near-term, credible, and measurable progress can be made. This program, managed by NASA Glenn represents the combined efforts of individuals from various NASA centers, other government labs, universities and industry.

NOTE: For a general introduction about the challenges of interstellar travel and such concepts as "warp drives" and "wormholes," visit our Warp Drive, When? site.

NASA Glenn Research Center

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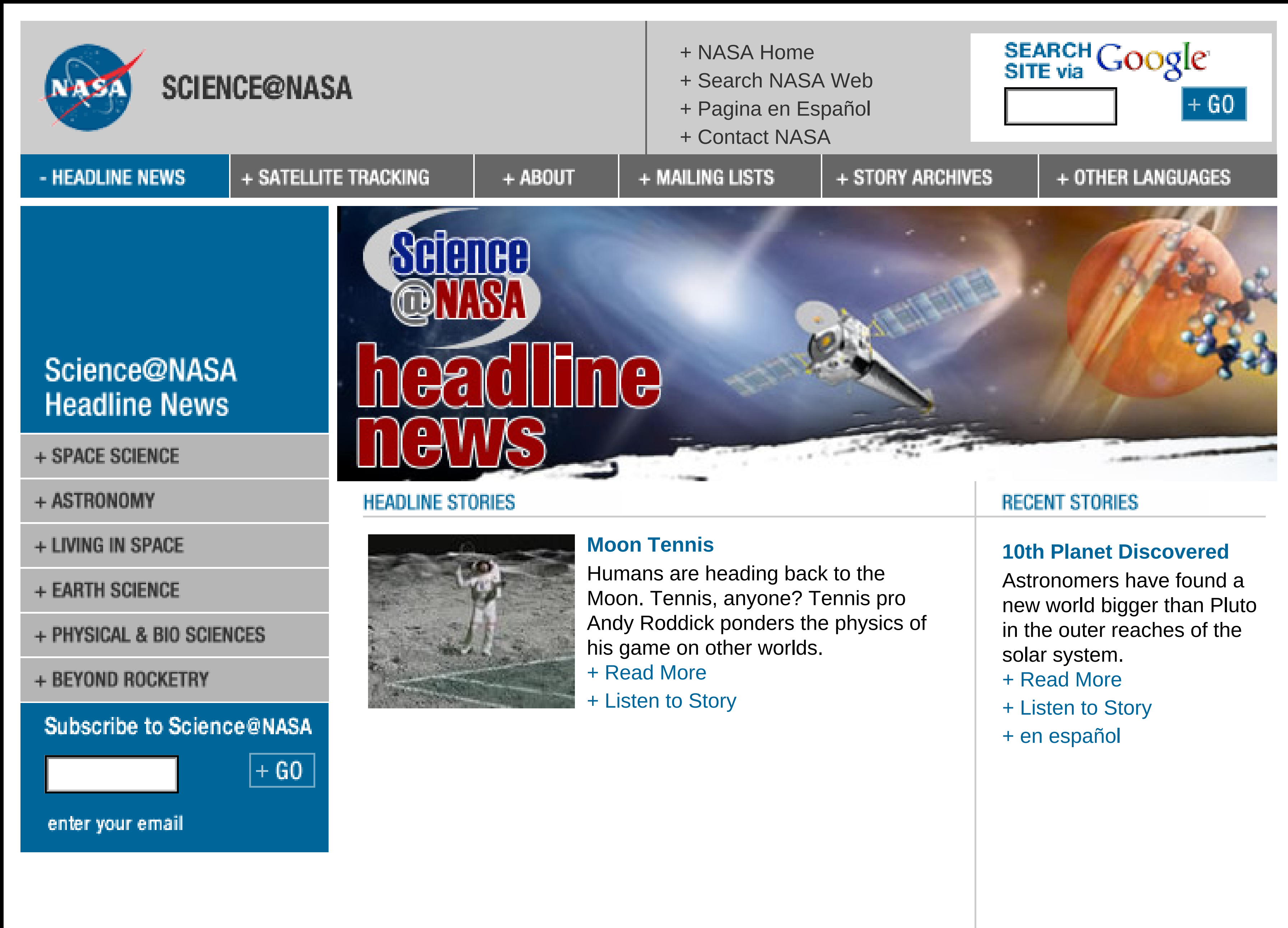
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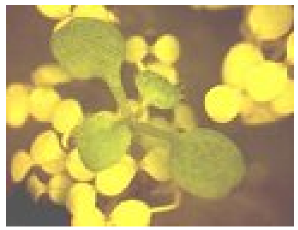

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Abandoned Spaceships

For the first time since the 1970s, a NASA spacecraft will get clear pictures of Apollo relics on the Moon.

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Curator: Bryan Walls
NASA Official: Ron Koczor
Last Updated: August 30, 2005
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Thousands of years ago, on a small rocky planet orbiting a modest star in an ordinary spiral galaxy, our remote ancestors looked up and wondered about their place between Earth and sky. Today, we ask the same profound questions:

- How did the universe begin and evolve?
- How did we get here?
- Where are we going?
- Are we alone?

Today, after only the blink of an eye in cosmic time, we are beginning to answer these questions. Space probes and space observatories have played a central role in this process of discovery.

Our missions and research generate most of the coolest news coming out of NASA. We are responsible for all of NASA's programs relating to astronomy, the solar system, and the sun and its interaction with Earth. Our science stretches from the middle levels of Earth's atmosphere to the beginning of the universe, billions of light years away.

Our web site serves our science community, educators, government decision-makers, and the public. We hope your visit is enjoyable. Thanks for stopping by!

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Check out the Vision for Space Exploration - we will be an integral partner, particularly in regard to robotic exploration of the Moon and Mars.

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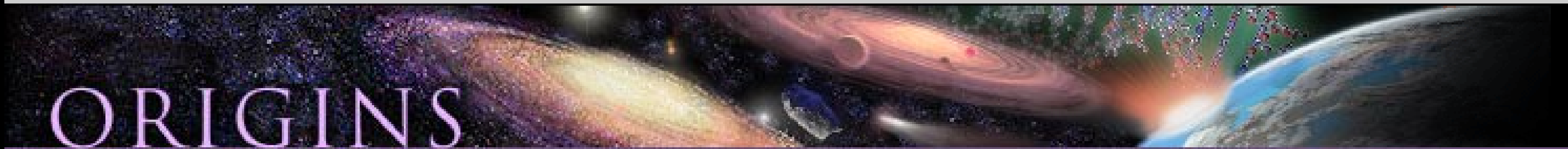
NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION



Where did we come from? *Are we alone?*

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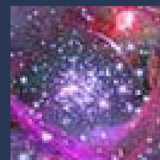
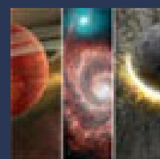


NASA's Hubble Weighs in on the Heaviest Stars in the Galaxy

Using NASA's Hubble Space Telescope, astronomers made the first direct measurement within our Milky Way Galaxy.



Spitzer Space Telescope Provides Visual Feast Online

The magic of NASA's Spitzer Space Telescope comes alive in an online interactive presentation.

Curator: Steve Unwin
Webmaster: Kristy Kawasaki
NASA Official: Mike Devirian
Last Updated: NaN undefined NaN
JPL Clearance: CL03-1374

WEEKLY UPDATE FOR 2 SEPTEMBER 2005:

GRAVITY PROBE B MISSION STATUS AT A GLANCE

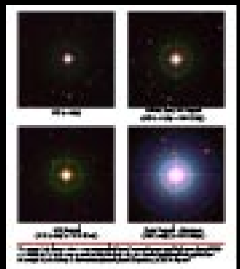
Item	Current Status
Mission Elapsed Time	500 days (71 weeks/16.4 months)
IOC Phase	129 days (4.2 months)
Science Phase	352 days (11.6 months)
Final Calibration Phase	19 days
Current Orbit #	7,376 as of 1:30 PM PST
Spacecraft General Health	Good
Roll Rate	Normal at 0.7742 rpm (77.5 seconds per revolution)
Gyro Suspension System (GSS)	All 4 gyros digitally suspended
Dewar Temperature	1.82 kelvin, holding steady
Global Positioning System (GPS) lock	Greater than 98.5%
Attitude & Translation Control (ATC)	X-axis attitude error: 140.0 marcs rms Y-axis attitude error: 186.4 marcs rms

Command & Data Handling (CDH)	B-side (backup) computer in control Multi-bit errors (MBE): 0 Single-bit errors (SBE): 8 (daily average)
Telescope Readout (TRE)	Nominal
SQUID Readouts (SRE)	Nominal
Gyro #1 rotor potential	+1.6 mV
Gyro #2 rotor potential	+0.9 mV
Gyro #3 rotor potential	-0.3 mV
Gyro #4 rotor potential	+1.8 mV
Gyro #1 Drag-free Status	Backup Drag-free mode (OFF during some calibration tests)

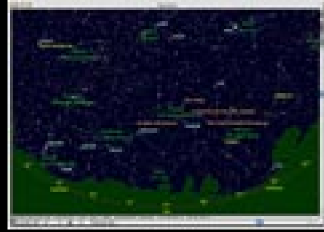
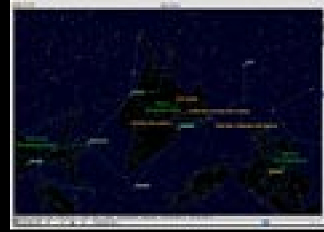
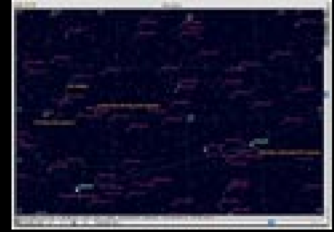
MISSION DIRECTOR'S SUMMARY

On Mission Day 500, the Gravity Probe B vehicle and payload are in good health and all subsystems are performing nominally.

As of today, there is still an ever-thinning film of superfluid helium in the Dewar, and thus calibration tests, which began 19 days ago, continued throughout this past week. Over the course of last weekend and early this week, we thrice slewed the telescope (and spacecraft) to “visit” the star HD 216635, which is about one degree northwest of IM Pegasi, and then back to IM Pegsi.



On Wednesday, we visited the star HR Pegasi (HD 216672), which is about 0.4 degrees west of IM Pegsi. We had previously visited this star during the Initialization and Orbit Checkout (IOC) phase of the mission in June 2004, as a test to confirm that the star we were using as the guide star was, in fact, IM Pegasi. (You can read about our previous visit to HR Pegasi in our archived weekly highlights for 11 June 2004. http://einstein.stanford.edu/highlights/hlindex.html)

Thus far during these final calibration tests, our visits to HD 216635 and to Zeta Pegasi were predominately in a north-south plane, relative to IM Pegasi. Our visit to HR Pegasi this past Wednesday was our first calibration test with a star located in the east-west plane, with respect to IM Pegasi. Continuing this line of exploration, yesterday and today we completed several visits to locations less than one degree west, and less than one degree east of IM Pegasi. No stars visible to the on-board telescope exist in these recently visited locations, so we used data from our star trackers and our standard navigational gyroscopes, which are accurate to within 20 arcseconds, to determine the positions of these “virtual stars.” Since the purpose of these calibrations is to evaluate the effects of telescope mis-alignments on the science gyros, greater pointing accuracy is not required for these excursions.

We have postponed our previous plans to slow down the spacecraft's roll rate until after the helium in the Dewar is fully depleted. Over this weekend, we will continue making calibration tests similar to those we have been performing, and if the helium lasts into next week, we will perform other types of calibration tests. Once the helium is depleted, the GP-B flight mission will officially end.

Tony Lyons, NASA's program manager for GP-B from Marshall Space Flight Center in Huntsville, AL, has been here at Stanford all week, participating with our team in these final days of the mission.

GP-B MISSION NEWS—THE FINAL DAYS

This past week marks a major transition point in the GP-B program. Just over 16.4 months after a picture-perfect launch on 20 April 2004, we will come to the end of the GP-B flight mission. Literally any day now, the supply of superfluid helium--the coolant that has maintained the cryogenic temperatures necessary for our SQUID gyro readouts to function--will be exhausted.



Right now, there is an ever-thinning layer of superfluid liquid helium lining the Dewar, and there will come a point where the last of this liquid helium has “sweated” out through the porous plug, leaving only helium gas inside the Dewar. (See our Mission News story of 29 July 2005 for a description of the porous plug http://einstein.stanford.edu/highlights/hlindex.html.) As this final helium gas begins to pas through the porous plug, the pressure in the Dewar will begin to drop, causing the temperature in the probe to rise. We don't know whether this transition will happen gradually or suddenly (as was the case with NASA's COBE spacecraft), but we will know that we have reached this point when our telemetry data shows a rise in the temperature sensors on the bracket that houses the SQUID gyro readout controllers and the temperature sensors on the telescope detector packages. When the temperature in the probe reaches about 7 kelvin, we will begin to lose superconductivity in the niobium gyro rotor coatings, and the SQUID gyro readouts will gradually cease to detect the London moments in the gyros. At this point, it be no longer be possible to determine the spin axis orientation of the science gyroscopes, although the Gyro Suspension Systems (GSS) will continue to indicate the position of each gyro rotor within its housing to great precision. Also, with no helium propellant left, the spacecraft will no longer be able to maintain a drag-free orbit.

The 650 gallons of helium that filled the Dewar at launch has lasted a few days more than the length of time planned. We collected 50 weeks of science data-just two weeks short of the year's worth of data we had hoped to collect. Furthermore, we lost less than 1% of the data collected to telemetry and/or spacecraft hardware problems. We have now completed all of the vital planned calibration tests that needed to be done with the gyro readouts still functioning, and we are using these final days of helium to perform additional tests that will be valuable to the data analysis now in process. In short, GP-B has been a remarkably successful mission.

There is an air of triumph here at Stanford, but there is also a note of sadness. Having become a very tight-knit team, we are saddened that today is the last day of work on GP-B for a number of our colleagues, especially those from Lockheed Martin Corporation. Thus, this afternoon, we all gathered in the conference room where we've been holding daily status meetings since before launch, and we spent a few minutes raising toasts to our successful mission and to the future endeavors of our colleagues who will be moving on to new jobs next week.

Regarding the GP-B spacecraft, the experiment, and the remaining members of the team, following is a brief overview of what's in store. Next Tuesday, when we return from the Labor Day holiday, GP-B will be a much quieter place. Our science team is already well into the long, painstaking process of analyzing the data. A small spacecraft operations crew, including several GP-B graduate students who are being cross-trained for these duties, will continue to monitor the spacecraft's system status, send commands to it when necessary, and regularly, though much less frequently, download various types of data via NASA telemetry satellites and ground stations.

We will use magnetic torquers--long electromagnets mounted on the spacecraft frame--to slow down the spacecraft's roll rate from 0.7742 rpm to 0.5 rpm or less and to control the spacecraft's orientation in orbit. For about two weeks, we will perform a number of tests on various electronic systems in the spacecraft. For example, we want to compare various performance characteristics of the GSS system after it has “warmed up” to its performance in a cryogenic superconductive state. Finally, in about a month, we will spin down all four science gyros to speeds slow enough that they will not be in danger of shattering, should they lose suspension and touch their housing walls. At this point, the spacecraft could be used by other scientists to make various non-relativitistic measurements. For example, it could be used for experiments in geodesy (measuring the shape of Earth's gravitational field) and aeronomy (measuring atmospheric density). We are in the process of exploring the interest in further use of the GP-B spacecraft for such experiments with a number of scientists.

One last note: All of us on the GP-B team are deeply saddened by the horrific disaster and unfathomable human tragedy that has been unfolding in Gulf Coast this past week. Our hearts and prayers go out to the countless victims.

UPDATED NASA/GP-B FACT SHEET AVAILABLE FOR DOWNLOADING

We recently updated our NASA Factsheet on the GP-B mission and experiment. You'll now find this 6-page document (Adobe Acrobat PDF format) listed as the last navigation link under "What is GP-B" in the upper left corner of this Web page. You can also **click here to download a copy.**

Drawings & Photos: The layered composite photo of the GP-B spacecraft was created by GP-B Public Affairs Coordinator, Bob Kahn, using Adobe Photoshop and Adobe Illustrator. The photo of the Dewar was taken by Lockheed Martin photographer Russ Underwood. The photos of the porous plug and SQUID are from the GP-B Image Archive here at Stanford. The sky chart images, showing the guide star IM Pegasi and its neighboring stars, were generated by the Voyager III Sky

Simulator from **Carina Software**. The star photos, as well as much of the information about these stars came from the various Web pages of the **Centre de Donnees astronomiques de Starsbourg--CDS**, including the **Simbad astronomical database** and the **Aladin interactive sky atlas**. Click on the thumbnails to view these images at full size.

MORE LINKS ON RECENT TOPICS

- **Track the satellite in the sky**
- **Photo, video & and news links**
- **Build a paper model of the GP-B Spacecraft**
- **Following the mission online**
- **Our mailing list—receive the weekly highlights via email**
- **The GP-B Launch Companion** in Adobe Acrobat PDF format. Please note: this file is 1.6 MB, so it may take awhile to download if you have a slow Internet connection.

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LIGO Livingston Observatory

California Institute of Technology
Massachusetts Institute of Technology

Supported by the National Science Foundation

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LIGO Newsletter

image courtesy of weather.com

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LIGO is supported by the National Science Foundation

Space Science Missions Under Study

These missions are in the study phase. They are either expected to eventually enter development, or are potential development starts selected under an Announcement of Opportunity.

ANITA Constellation-X DUO EUSO GEC Geospace IBEX JIMO JMEX Juno JWST Kepler LISA Mag Constellation Mag Multiscale Mars Science Laboratory 2009 Mars - beyond 2009 Moonrise NEXUS NuSTAR Phoenix SDO Sentinels SIM Solar Probe TPF WISE

You may also be interested in some very preliminary mission concepts.

Antarctic Impulsive Transient Antenna

ANITA is a long-duration balloon payload that would detect radio waves emitted when high-energy neutrinos interact in the Antarctic ice shelf. ANITA was selected for study as a potential Small Explorer mission of opportunity in November 2003.

Constellation-X

Constellation-X has been designed to perform X-ray spectroscopy with unprecedented sensitivity and spectral resolution. The measurement of large numbers of X-ray spectral lines in hot plasmas leads to determining the elemental composition, temperature, and velocity of the emitting matter. Astronomers will determine the flow of gas in accretion disks around black holes in active galactic nuclei and in binary X-ray sources, measure the population of newly created elements in supernova remnants, and detect the influence of dark matter on the hot intergalactic medium in clusters of galaxies. Constellation-X is identified in the OSS Strategic Plan.

Dark Universe Observatory

The DUO mission would include seven X-ray telescopes to measure the dark matter and dark energy that dominate the content of the universe, with 100 times the sensitivity of previous X-ray studies. DUO was selected for study as a potential Small Explorer mission in November 2003.

Extreme Universe Space Observatory

EUSO would detect the highest-energy cosmic rays known by using the entire Earth as a particle detector. EUSO will look down on the Earth's atmosphere to observe the characteristic blue light that high-energy cosmic rays generate after hitting the Earth's atmosphere. EUSO is under study by the European Space Agency for flight on the Columbus module of the ISS, and NASA would provide the large Fresnel lens for the telescope.

Geospace Missions

The goal of the Geospace missions is to increase understanding of how the Earth’s ionosphere and magnetosphere respond to changes due to solar variability. Geospace is a component of the Living with a Star initiative.

Global Electrodynamic Connections

GEC is planned as a cluster of 4 satellites, combined with ground-based observations, that will make systematic multi-point measurements to complete our understanding of the roles played by the ionosphere and thermosphere in the Sun-Earth connection. GEC is a future Solar Terrestrial Probe mission.

Interstellar Boundary Explorer

The IBEX mission would include a pair of cameras to image the boundary between the solar system and interstellar space with 100 times the sensitivity of previous experiments. IBEX was selected for study as a potential Small Explorer mission in November 2003.

James Webb Space Telescope

James Webb Space Telescope (formerly the Next Generation Space Telescope) is designed for observations in the far visible to the mid infrared part of the spectrum. This wavelength coverage is different from that of the HST which covers the range from the ultraviolet to the near infrared. JWST will probe the era when stars and galaxies started to form; it will also address many other astronomical questions.

Jupiter Icy Moons Orbiter

JIMO is an ambitious mission to orbit three planet-sized moons of Jupiter -- Callisto, Ganymede and Europa -- which may harbor vast oceans beneath their icy surfaces. JIMO would orbit each of these moons for extensive investigations of their makeup, their history and their potential for sustaining life. NASA's Galileo spacecraft found evidence for these subsurface oceans, a finding that ranks among the major scientific discoveries of the Space Age. The JIMO mission also will raise NASA's capability for space exploration to a revolutionary new level by pioneering the use of electric propulsion powered by a nuclear fission reactor.

Jupiter Magnetospheric Explorer

JMEX is a telescope intended to study Jupiter's aurora and magnetosphere from Earth orbit. JMEX was selected for study as a potential Small Explorer mission in November 2003.

Juno

To be placed in a polar orbit about the planet Jupiter, Juno is being designed to investigate the existence of an ice-rock core, determine the global water and ammonia abundances in Jupiter's atmosphere, study convection and deep wind profiles in the atmosphere, investigate the origin of the jovian magnetic field, and explore the polar magnetosphere. Juno is a candidate of the New Frontiers program.

Kepler

The Kepler mission is a space telescope specifically designed to detect Earth-sized planets around stars in the Sun's neighborhood of the galaxy. By monitoring 100,000 stars over a four-year mission, Kepler could detect up to 500 Earth-sized planets and up to 1000 Jupiter-sized planets. Kepler was selected in December 2001 as a Discovery mission.

Laser Interferometer Space Antenna

LISA is a gravity wave telescope which will open up one of the last non-electromagnetic channels for studying the Universe. Its goal is to detect gravitational radiation with periods of minutes to hours such as that produced by two coalescing massive black holes in a distant galaxy. LISA will also provide an unprecedented test of strong field general relativity theory. LISA is identified in the OSS Strategic Plan.

Magnetospheric Constellation

The mission of MC is to fly 50-100 (very small) nano-satellites in a constellation, to make multiple remote and in-situ measurements in space and revolutionize the scientific investigations of key physical processes in the Sun-Earth medium. MC is a future Solar-Terrestrial Probe mission.

Magnetospheric Multiscale

Broad regions of the Earth's magnetosphere are connected by fundamental processes operating in thin boundary layers. Processes of vastly different scale sizes can interact strongly. Understanding these fundamental processes requires multipoint measurements that uniquely separate temporal and three-dimensional spatial variations. The MMS mission goal is to make those necessary measurements with a five spacecraft constellation in highly eliptical orbits. In September 2003 we announced the selection of two proposed mission concepts for further study. MMS is a future Solar-Terrestrial Probe mission.

Mars Science Laboratory 2009

NASA proposes to develop and to launch a roving long-range, long-duration science laboratory that will be a major leap in surface measurements and pave the way for a future sample return mission. The mission will also demonstrate the technology for "smart landers" with accurate landing and hazard avoidance, in order to reach what may be very promising but difficult-to-reach scientific sites.

Mars missions beyond 2009

In the second decade of the century, NASA plans additional science orbiters, rovers and landers, and the first mission to return samples of Martian rock and soil to Earth.

Moonrise

Moonrise proposes to send a pair of landers to locations near the moon's south pole, a region is believed to harbor materials from the moon's mantle. The landers as currently planned would return over two kilograms of lunar materials. Moonrise is a candidate of the New Frontiers program.

Normal-incidence Extreme Ultraviolet Spectrometer

NEXUS is a solar spectrometer mission, with major advances in sensitivity and resolution to reveal the cause of coronal heating and solar wind acceleration. NEXUS was selected for study as a potential Small Explorer mission in November 2003.

Nuclear Spectroscopic Telescope Array

NuSTAR is a telescope intended to carry out a census of black holes with 1000 times more sensitivity than previous experiments. NuSTAR was selected for study as a potential Small Explorer mission in November 2003.

Phoenix

This mission proposes to conduct a stationary, in situ investigation of volatiles (especially water), organic molecules and modern climate. It aims to "follow the water" and measure indicator molecules at high-latitude sites where Mars Odyssey has discovered evidence of large ice concentrations in the Martian soil. Phoenix was selected for study as a potential Mars Scout mission in December 2002.

Sentinels

To improve accuracy of space weather predictions, the Sentinels mission will characterize the environment through which solar disturbances propagate and study their evolution. Sentinels is a future mission in our Living with a Star initiative.

Solar Dynamics Observatory

How does the solar interior vary through a solar cycle? How does this variation manifest itself in the structure of the Sun's corona and heliosphere? What is the origin and effect of sunspots and solar active magnetic regions? SDO is designed to answer these and other questions, and is a future mission in our Living with a Star initiative.

Solar Probe

Solar Probe, which will make the first ever measurements within the atmosphere of a star, will provide unambiguous answers to long-standing fundamental questions about how the corona is heated and how the solar wind is accelerated. The spacecraft, which will provide both imaging and in situ measurements, is targeted to pass within 3 solar radii of the Sun's surface.

Space Interferometry Mission

SIM will be the world's first long-baseline optical interferometer in space, and a technological precursor to the Terrestrial Planet Finder. With its unprecedented astronomical accuracy and high spatial resolution, SIM will allow indirect detection of planets through observation of thousands of stars, and will investigate the structure of planetary disks.

Terrestrial Planet Finder

TPF is currently envisioned as a long baseline infrared interferometer, operating in the 7-20um wavelength range. This range is an excellent region for the direct detection of terrestrial planetary companions to other stars, and also for detecting spectral lines which might indicate a habitable planet.

Widefield Infrared Survey Explorer

WISE is an infrared telescope designed to survey the entire sky with 1,000 times more sensitivity than previous missions. WISE would be led by Edward L. Wright of the University of California, Los Angeles. WISE (originally named the Next Generation Sky Survey, NGSS) was selected as a potential Mid-Class Explorer (MIDEX) in April 2002; in March 2003 WISE was approved for further study. A decision on proceeding to flight development with WISE will be made in 2004.

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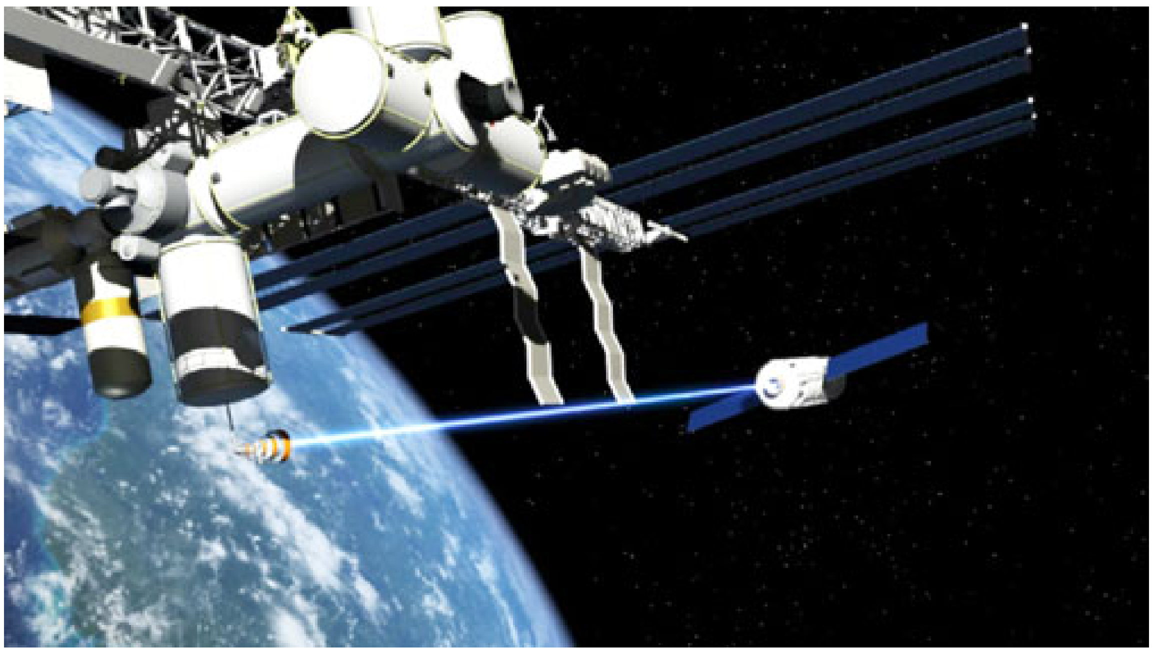
NIAC
NASA Institute for Advanced Concepts



Who We Are

NIAC seeks proposals for revolutionary aeronautics and space concepts that could dramatically impact how NASA develops and conducts its missions. It provides a highly visible, recognizable, and high-level entry point for outside thinkers and researchers. NIAC encourages proposers to think decades into the future in pursuit of concepts that will "leapfrog" the evolution of current aerospace systems. While NIAC seeks advance concept proposals that stretch the imagination, these concepts should be based on sound scientific principles and attainable within a 10 to 40-year time frame.

NIAC in the News

In a cover story "To Infinity and Beyond: Can a band of true believers blast America's manned space program out of low Earth orbit into a stellar future?" (Washington Post Magazine, May 15) Joel Achenbach presents the results of months of research and interviews with visionaries both inside and outside of NASA. The long and very detailed article ends with a focus on NIAC, including references to NIAC-funded concepts such as tethers, the space elevator, the Lunar Elevator, and the MagBeam.

Important Announcements

October 2005 Annual Meeting

The NIAC 7th Annual Meeting will be held at the Omni Interlocken Resort located between Denver and Boulder, Colorado on October 10-11, 2005. Confirmed keynote speakers include Courtney Stadd, Dr. Paul MacCready, and Dr. Fred Adams. NIAC Phase I, Phase II and Student Fellows will present their work. Click here for meeting details and registration.

The NIAC Student Fellows Prize Winners

The NASA Institute for Advanced Concepts (NIAC) seeks to identify creative and innovative undergraduate students who have shown exceptional creativity and promise for future success in building visions of the future. The NIAC Student Fellows Prize (NSFP), sponsored by Universities Space Research Association and managed by NIAC, was initiated in 2005. View the winners of the NIAC Student Fellows Prize for Academic year 2005-2006 here.

CP 05-01

NIAC is pleased to announce that 12 Phase I concepts have been selected for an award from the 158 proposals that were submitted in response to Call of Proposals, CP 05-01. Additional information about the awards will be available in the near future. View the selected studies here.

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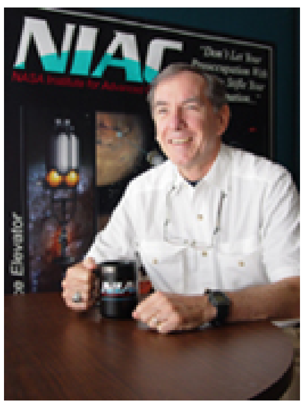

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NIAC is an independent entity funded by NASA