

Prospects for Breakthrough Propulsion from Physics

(Available as NASA TM-2004-213082)

May-2004

Marc G. Millis

NASA Glenn Research Center, Cleveland Ohio 44145

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 though 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 Congressional 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 approaches. 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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Last update: May 13, 2004