A Review of Past Insights by Robert L. Forward, PhD: Emerging Technologies and Future Concepts

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Abstract. A review of various technologies discussed by Dr. Robert Forward is presented as a tribute to Dr. Forward, and is based on selections from his writings and those of subsequent investigators. Some emphasis is placed on the new frontiers of space propulsion, power and communication. Many of these concepts and technologies are presented within the STAIF 2004 "1st Symposium on New Frontiers and Future Concepts." These range from highly speculative notions to hardware that has now been demonstrated in space flight. Among these concepts and technologies to be discussed are future communications, antimatter propulsion, space elevators and tethers, beamed energy propulsion, and emerging gravity theories and concepts.

INTRODUCTION

The wonders that take place every day of our lives would have bewildered most people in the earlier 1960s, before manned space flight, and would have raised cries of "black magic" before the 1900s. However, new ideas cannot come to pass without the proper foundation. If not for a young engineer in the early 1900s been driven by the dream of traveling to space, there may never have been a NASA by the early 1960s. In the spirit of Arthur Clarke's observation in *Profiles of the Future* (Clarke, 1967) that sufficiently advanced technology would be indistinguishable from magic, Dr. Forward discussed a variety of propulsion, power and communication related technologies in a book entitled *Future Magic* (Forward, 1988), updated in 1995 as *Indistinguishable from Magic*. (Forward, 1995) Many of these concepts were also reviewed in greater detail in a series of reports written for the then Air Force Rocket Propulsion Laboratory (Forward, 1982 and 1987). Some of the items described, tethers in particular, show continuing promise and are the focus of significant work. In some cases, Forward's discussion, in the context of interstellar propulsion, was cursory in that he did not think the technology was promising enough for interstellar use, nor perhaps innovative enough to qualify as "magic" for his readers. In other cases, a quick calculation showed that some, while "magical" enough, were unlikely to be an improvement over better-known methods. Others fell short because they required "unobtanium" or the theory simply wasn't developed enough to proceed further.

> *Aided by existing theories, we can guess at these magical wonders, but we are very uncertain of how we will attain the technologies that will be needed to turn them from wishful magic into hard reality. The theory on which some future magic is based may be wrong and it could never come to pass. The theory may be correct, but the technology needed to achieve the goal may require a material that just doesn't exist. It may be that the theory is correct and the technology is impossible, but we decide that the effort involved is more than it is worth. Or - it may be we will be too busy exploring other realms of future magic (Forward, 1988).*

Whether genitive of practical work or not, Dr. Forward's exploration provided an interesting introduction to the breadth of the field as it existed in 1988. Although, the science and technology areas to be discussed here were addressed in *Future Magic* (Forward, 1988); the reader is directed toward Dr. Forward's newer book,

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Indistinguishable from Magic (Forward, 1995), its bibliography and the general literature for more information on these ongoing research areas.

We will concentrate on some of the more productive and interesting of these concepts and technologies that have come forward over the last fifteen years. Many of these, included in the "1st Symposium on New Frontiers and Future Concepts" at the Space Technology and Applications International Forum (STAIF) 2004, are still considered to be emerging concepts. Others, such as nuclear propulsion (not discussed) and beamed energy propulsion, have in the last few years broken out into worldwide conferences. Antimatter, while shown to have daunting problems as a propulsion energy source, proved to have numerous other potential uses. In such research lies the impetus for this retrospective of Dr. Forward's insight into the many developing concepts and technologies he familiarly called "Future Magic." Due to limited space, only a small amount of information is presented.

FUTURE COMMUNICATION

Dr. Forward gave the following description of the birth of radio as an analogy for the development of future communications technology:

> *In 1885, after a great deal of experimentation and effort, Heinrich Hertz was the first one to make and detect what he called "electric waves" in the laboratory. Considering how difficult it was for Heinrich Hertz to make and detect his electric waves, he would have been astounded to know that within a few generations his discovery would be the force that animates the future-magic boxes that now bring music into our cars and MTV into our homes (Forward, 1988).*

Compared to the now mature field of electromagnetic communications, Dr. Forward discussed such sources of future communication--gravitational waves, neutrino, and tachyons--that are in as at least as early a phase of investigation as radio was in 1885. It is noted that Forward fully recognized that the well-tested Lorentz transformation shows that faster than light communication, such as by tachyons, creates paradoxes in which A causes B in some frames of reference and B causes A in other frames of reference (Forward, 1988). At the time of *Future Magic,* his hopeful speculation, similar to Goff's (2004), was that the universe could somehow require such events to be logically consistent. He did not however, spend much time with proposals or proposers that insisted that relativity was wrong without offering a viable alternative.

High frequency gravity wave (HFGW) communication was recently discussed at the Gravitation-Wave Conference (International HFGW Working Group) held at the MITRE Corporation, May 6-9, 2003, and many references are present in the proceedings. Further, several HFGW papers (Baker, 2004 a, b, c; Portilla 2004; Fontana, 2004) and a paper using entangled photons for faster than light (FTL) communications (Goff, 2004) will be presented at STAIF 2004 in the "1st Symposium on New Frontiers and Future Concepts."

ANTIMATTER PROPULSION

Forward was very interested in the possibility of using antimatter to store energy for propulsion, and became the driving force behind a project, under Air Force leadership that involved the Rand Corporation and several universities, to take a serious look at making and using antimatter. The technical version of the results of this effort was published by Rand Corporation (Augenstein et al., 1987) in the same year as *Future Magic* (Forward, 1988). Forward also wrote a popular account, *Mirror Matter*, with science writer Joel Davis (Forward and Davis, 1988). They envisioned an antiproton factory with a yield of .01%, electrical energy in to mass energy to produce antiprotons out, which in 1987 dollars, was about $10M a milligram. The antiprotons would be trapped in magnetic fields, cooled with electrons, and combined (on the fly, in perfect vacuum) with positrons to form antihydrogen. The antihydrogen would be cooled with lasers into frozen hydrogen, which would be stored as antihydrogen ice using electromagnetic fields to isolate it from external contact. Small amounts of antihydrogen would be electrostatically pulled from the ice and used as needed.

The main use was propulsion. Small amounts of antimatter would heat large amounts of propellant to very high exhaust velocities in a variety of conjectured devices. These, roughly, would perform like nuclear rockets without the reactor. But a wide variety of other uses were also considered, including physics research, remote analysis (from annihilation x-rays and gamma spectra), tomography, and radiotherapy. There is some poignant irony in that Dr. Forward died of a brain tumor that might have been treatable with an antiproton beam. Much of the efforts on antimatter have been spent in areas of particle beam manipulations, atomic chemistry and laser cooling that were relatively near term; these techniques have already produced antihydrogen atoms (Amoretti et al., 2002). Also laser cooled "Bose-Einstein condensates" have achieved temperatures and vacuums that approach those needed for antihydrogen containment (Levi, 2001). The biggest problems with antimatter propulsion are production yield and use. Forward's $10/milligram looks very optimistic, although some experts suggested that a yield of 1/400 might be theoretically possible. Antihydrogen annihilation produces a shower of nuclear particles that are hard to contain and convert into a directed exhaust, thermal or electrical energy with any significant efficiency or safety (Nordley, 1992). Possibly the most promising antimatter propulsion idea comes from Dr. Gerald Smith (Lewis et al., 1990). Antiprotons would ignite fission/fusion pellets, bypassing thus far unsuccessful efforts to ignite fusion pellets with lasers. Dr. Smith's propulsion system would perform much like the pulsed fusion systems envisioned by several investigators.

Neglecting production shortcomings, storage is identified as a key enabling technology for all antimatter-related operations. This is the current focus of NASA-MSFC's effort to design and fabricate a portable device capable of holding up to 10^{12} particles. Hardware has been assembled and initial tests are underway to evaluate the trap behavior using electron-gun-generated positive hydrogen ions. Ions have been stored for tens of minutes, limited by observed interaction with background gas (Martin, 2004).

SPACE ELEVATORS AND TETHERS

Dr. Forward wrote of compressional towers and tensional tethers (sky hooks) as "magic beanstalks" on which space elevators would climb above the atmopshere, echoing a "stairway to heaven" theme throughout mythology. Little has been accomplished in the area of space elevators, even though Dr. Forward himself pointed out that, under reasonable engineering limits, the compressional strength of known materials allows very high towers. Steel towers could be built up to 6 kilometers high and aluminum ones to almost 10 kilometers high, compared to Mount Everest (compressed rock) which is 8.8 kilometers high. Using a 6-kilometer base, a 40-kilometer tower could be built with graphite composite materials - some 100 times taller than the tallest building, but less than the 50-kilometer altitude that designates the boundary of space (Forward, 1988). Towers levitated by circulating, magnetically confined, pellet streams could be built to orbital atltitudes (Forward, 1988).

Tethers, on the other hand, have been proposed in many different designs (Cosmo and Lorenzini, 1997), some of which have been tested in space (Carroll, 1995). In 1991, Forward (1991) combined a number of rotating tether concepts published by others (Moravec, 1977; Stern, 1988) to show that three rotating tethers would suffice to move payloads from a suborbital trajectory just above the Earth's atmosphere to the surface of the Moon and back again, without any use of rockets except to get out of the Earth's atmosphere. The three tethers consisted of a rotating tether in a nearly circular Low Earth Orbit (LEO), a rotating tether in a highly Elliptical Earth Orbit (EEO), and a rotating "Lunavator" tether cartwheeling around the Moon in a circular orbit whose altitude is equal to the tether arm length, resulting in the tip of the tether touching down on the lunar surface (Hoyt. 1997a, b, c; Hoyt and Forward, 1997). Forward also worked on systems to send payloads from planets by means of a system of rotating tethers in elliptical orbits about each planet.

> *A payload is picked up near periapsis and tossed later still near periapsis, at a velocity sufficient to give the payload a substantial hyperbolic excess velocity. At the destination planet, it may be caught near periapsis and released a short time later in a bound trajectory. The system works in both directions and is reusable. Kinetic energy lost by the throwing tethers can be restored either by catching incoming payloads, by propellantless tether propulsion methods, and/or high specific impulse propulsion systems. In preliminary studies with simplified assumptions, tethers with tip velocities of 3 km per second may send payloads to Mars in as little as 70 days if aerobraking is used at Mars to dissipate excess relative velocity and the orbital phasing is favorable. (Nordley and Forward, 2001)*

The recent prospect of ultrahigh carbon nanotube tether material (Yu et al., 2000) would make possible a "Teravator" with 8 km/s tip speed. Using models for the MERITT system, (Nordley, 2001; Nordley and Forward, 2001), we find that such a tether could pick up payloads from the surface of the Earth and release them on interplanetary trajectories with hyperbolic excess velocities of about 15 km/s; enough to get a payload from Earth to Mars in fifty days at a favorable opposition.

Tethers Unlimited, the company Dr. Forward started with Dr. Robert Hoyt for development of tether technology, has several current contracts for research and development of tether applications. Much of the work has focused on electrodynamic tethers, wherein the tether supports a long conducting wire and electron emitters/collectors. Current flowing through the wire interacts with the Earth's magnetic field by the Lorentz force, creating drag or acceleration. For current tether information, see the Tethers Unlimited, Inc. web site at http://www.tethers.com/index.html.

BEAMED ENERGY PROPULSION

In his chapter on "Magic Starships," Dr. Forward discusses a class of spacecraft that do not take along any energy source or reaction mass, or even an engine. These beamed-power propulsion systems leave the heavy power producing parts on the ground or in orbit about the earth. Power is beamed, or momentum is transferred to the spacecraft by means of material particles, laser light, or microwaves. The beam may be used to accelerate a minimal amount of on-board propellant or simply push a reflector or sail. Most of Forward's attention went into photon reflecting sail technology, which still shows promise. Since *Future Magic*, it has been shown that variable velocity particle beams could transfer essentially all of their momentum and energy to a spacecraft (Nordley, 2001) and microwaves, which can be generated with high efficiency, have accelerated small test sails at several gravities (Benford et al., 2001). Activity in the field has been sufficient to warrant an annual symposia (See http://www.lpw.uah.edu/Home.html), including a "Second International Symposium on Beamed Energy Propulsion," scheduled for October 2003. (See http://nana.ifs.tohoku.ac.jp/isbep2/)

GRAVITY THEORIES AND CONCEPTS

Dr. Forward, in his section on "Magic Gravity," reminds us that:

> *From birth to death, gravity pervades our life. Our every step, day in, day out, is a struggle against this relentless force. Is there some future-magical method to control gravity (Forward, 1988)?*

Generally, this chapter did not lead to any straightforward approach to conquering the age-old puzzle we call gravity. At best is Dr. Forward's reference to general relativity and quantum mechanics.

> *The Einstein theory of gravity says that gravity behaves the same way as electricity (Forward, 1988).*

> *The new quantum theory of gravity will be even more complex than the Einstein theory of gravity (Forward, 1988).*

Here we carry this theory a bit farther by noting that some researchers believe that gravity should exhibit quantum behavior on the Planck scale (Ng, 2003; Markopoulou, 2002). Because of this extremely small scale, quantum gravity is usually regarded as being far away from observational tests. The different approaches to quantum gravity have to be judged on grounds of internal consistency and their ability to solve conceptual problems with theories based on larger scale observations of the real world (Bojowald, 2003). Observational constraints and the mathematical complexity of general relativity are such that a single completely satisfactory quantum theory of gravity has not emerged yet, though some investigators see promising approaches in loops, strings, and information theory (Smolin, 2000).

High temperature superconductors (HTSC) could provide a link to gravity in that quantum gravity events may affect quantum systems that operate at the macroscopic scale, in effect creating a macroscopic "memory" of the event. Theories connecting electromagnetic radiation to gravitational fields through quantum interactions associated with devices called "superconducting Josephson junctions" were proposed as early as 1966 by Dewitt (1966). In a series of papers in the early 1980s, Anandan (1981) and Chiao (1982) considered the possibility of constructing antennas for gravitational radiation, using Josephson junctions as transducers. In 1983, Ross (1983) derived the modified "London equations" for a superconductor in a gravitational field, and showed that these equations are consistent with the results found earlier by DeWitt (1966). In the early 1990s, Li and Torr (1990, 1992, and 1993) derived a similar relationship involving gravitomagnetic and gravitoelectric coupling to gravity. In 1990, Peng and Torr (1990 and 1991) used the generalized London equations to treat the interaction of a bulk superconductor with gravitational radiation, and concluded that such a superconducting antenna would be many orders of magnitude more sensitive than a Weber bar (which was, incidentally, Forward's Ph.D. thesis project). To date, only a few experiments have attempted to test these predictions.

In 1992, Podkletnov and Niemen (1992) reported gravity-like forces from a type II YBCO superconductor that was spun to very high speeds and subject to both radio frequency energy and varying magnetic fields. However, skepticism over a second paper (Podkletnov, 1997) has lead many to disbelieve the results. This has produced many papers on the "pros and cons" of these experiments, but no real effort has been made to repeat the experiments in their entirety, mainly due to the size and rotational speeds of the superconductor.

Another area that warrants mentioning is the work by Vargus and Datta (Vargus 2004; Datta and Vargus, 2004). Vargus (2004) studied the interplay of Einstein's Gravitation (GR) and Maxwell's Electromagnetism, where the distribution of energy-momentum is not presently known, and answers "yes" to the question, " Is electromagnetic gravity control possible?" Vargus' work indicates that gravity forces exist in reference frames where there is a change in energy with a change in distance. The experiment preformed by Datta showed a gravity force within a gradient electrostatic field that could not be explained by other sources (Datta and Vargus, 2004). The experiment was preformed in a nitrogen environment and needs to be repeated in a vacuum to rule out reactions with the environmental gas, even though it seems unlikely. A successful vacuum experiment could lay the groundwork for the validation of Vargus' theoretical work (Vargus 2004).

ZERO POINT ENERGY

In the "Future Speculations" chapter of *Future Magic* (Forward, 1988), Dr. Forward explored concepts for getting and storing energy in the Zero Point Field (ZPF), referring to the non-zero minimum energy state of vacuum in quantum electrodynamics. If, as he found likely, the field is conservative, it could not be used to generate energy, but it might be used to store energy via the Casimir effect verified this. In theory, "Empty" space is filled with ephemeral waves of various frequencies that press on objects in space isotropically and so normally cancel each other out. However, two material objects placed close together will exclude low frequency waves, reducing the pressure between them. The Casimir experiment verified this (Casimir et al, 1948). Forward speculated that foliated books of thin leaves, or spirals of thin metal, could be "inflated" with electric charge which would then flow out as the Casmir force brought the conductors together, so forming a kind of storage battery. But calculations showed that the amount of energy stored per unit mass was not competitive with existing energy storage devices. Other experiments with the ZPF are still far from a technological reality. We point the reader to the work by Haisch et al., (2003). See also work at the California Institute for Physics and Astrophysics (http://www.calphysics.org/).

FORWARD'S VIEW OF TECHNOLOGICAL PROGRESS

Dr. Forward thought that innovative scientific theory and engineering ideas should be given a fair trial, and not immediately dismissed for intuitive or political reasons. He was concerned that research funding levels, which strongly influence the course of future technological advances, tend to reflect political fears rather than scientific and technological merit, and that the development of potentially valuable technology is delayed when this happens.

Forward was well aware that innovative concepts face a burden of proof and that to be real, they must be testable. Just because something is an unconventional idea does not mean that it is a good unconventional idea. His point was that, if progress is to occur, objections to testing new ideas must meet the same standards of rigor as the ideas themselves, and that untested ideas cannot be said to have failed. Skeptical scientists may believe they...

...have a legitimate scientific reason for avoiding discussion. The taboo topics have been dreamed up by native human minds, and just because someone can think of a concept and give it a name does not make it real. These skeptical scientists do not see any "handles" by which they could grapple with these ill-formed concepts in order to understand them from a logical scientific point of view. Without that understanding, it is impossible to prove or disprove the reality of the concept (Forward, 1988).

Continuing Forward's paradigm of giving innovative and unconventional ideas in advanced propulsion a fair try, the STAIF 2004 "1st Symposium on New Frontiers and Future Concepts" has been established as an attempt to bring the government, academic, and the commercial sectors together in a forum that presents them with cutting edge ideas in space propulsion and challenges them, individually or cooperatively, to fund the research needed to check them out.

CONCLUSIONS

Of the technological areas considered in *Future Magic*, it should come as little surprise that those involving innovative use of well-founded science (antimatter, tethers, beamed energy propulsion) have had the most success in the experimental stage. All have had substantial "giggle factors," as Forward used to describe a common political and management reaction to unconventional concepts. But, however slowly, physics will win out. The question that arises is: which additional directions do we pursue? Forward pointed out that development funding choices are made by people who, placed in positions as the gatekeepers to science and technology, respond to the politicians controlling the funding, public opinion, fear of the unknown, and sometimes the shortsighted turf politics of research and development organizations. It takes a great deal of communication and persistence to make something actually happen.

In *Future Magic* as in his advisory work on advanced propulsion, Forward asked, basically, three questions.

1. Is the scientific basis of the concept sound, or does it ignore a substantial body of work?
2. What are the benefits to developing this technology over existing technologies?
3. Do the prospective benefits justify the cost of research needed to ascertain them?

Dr. Forward saw many possibilities that were then only a glimmer in the eyes of a few scientists brave enough to promote unconventional concepts. His approach was to evaluate with an open mind and demand that criticism meet as high a standard of scientific rigor as those proposing the concepts were expected to meet. We find this approach to advanced propulsion technology as important a part of Forward's legacy as any of the "Future magic" about which he wrote.

REFERENCES

Amoretti, M., et al., "Production and Detection of Cold Antihydrogen Atoms," *Nature* 419, 2002, 456–459.

Anandan, J., "Gravitational and Inertial Effects in Quantum Fluids," *Phys. Rev. Lett*. 47, 463, 1981; (Corrections in *Phys. Rev. Lett.* 52, 401,1984).

Augenstein, B. W., ed. (1988) *Proceedings of the Antiproton Science and Technology Workshop*, AFAL-CP-88-002, held at RAND Corporation, Santa Monica, CA, 6-9 Oct. 1987.

Baker, Robert M.L., "Precursor Experiments Regarding the Generation of High-Frequency Gravitational Waves (HFGW) by Means of Using an Array of Micro-and Nano- Devices," in these *Proceedings of Space Technology and Applications International Forum (STAIF-2004)*, edited by M. S. EL-Genk, American Institute of Physics, Melville, New York, 2004a.

Baker, Robert M.L., "Precursor Proof-of Concept Experiments for Various Categories of High-Frequency Gravitational Wave (HFGW) Generators," in these *Proceedings of Space Technology and Applications International Forum (STAIF-2004)*, edited by M. S. EL-Genk, American Institute of Physics, Melville, New York, 2004b.

Baker, Robert M.L., "An Experimental Program for High-Frequency Gravitational Wave (HFGW) Optical Applications," in these *Proceedings of Space Technology and Applications International Forum (STAIF-2004)*, edited by M. S. EL-Genk, American Institute of Physics, Melville, New York, 2004c.

Benford, James, et al., "Spin and Deflection Measurements of Microwave-Driven Sails," NASA JPL/MSFC/UAH 12th Annual Advanced Space Propulsion Workshop, University of Alabama in Huntsville, Alabama, April 3-5, 2001.

Bojowald, Martin and Hugo A. Morales-Tecotl, "Cosmological applications of loop quantum gravity," *ArXiv: gr-qc/0306008* 1 2 Jun 2003.

Carroll, Joseph A., "SEDS Deployer Design and Flight Performance," WSEDS-A-1, 4th International Conference on Tethers in Space, Washington, DC, April 1995.

Casimir, H. B. G. and D. Polder, "The Influence of Retardation on the London-van der Waals Forces," *Phys. Rev*. 73 .360 (1948)

Clarke, Arthur Charles, *Profiles of the Future,* Bantam Science and Mathematics SA12, 1967.

Chiao, R.Y., "Interference and inertia: A superfluid-helium interferometer using an internally porous powder and its inertial interactions," *Phys. Rev. B* 25, 1655, 1982.

Cosmo, M. L. and E. C. Lorenzini, *Tethers In Space Handbook, Third Edition,* AIAA, Washington December 1997.

Datta, Timir and Jose Vargus, "A Gravitational Experiment Involving Inhomogeneous Electric Fields" in these *Proceedings of Space Technology and Applications International Forum (STAIF-2004)*, edited by M. S. EL-Genk, American Institute of Physics, Melville, New York, 2004.

Dewitt, B. S., "Superconductors and Gravitational Drag," *Phys. Rev. Lett.* Vol. 16, No. 4, 1092,1966.

Fontana, Giorgio, "Design of a Quantum Source of High-Frequency Gravitational Waves (HFGW) and Test Methodology," in these *Proceedings of Space Technology and Applications International Forum (STAIF-2004)*, edited by M. S. EL-Genk, American Institute of Physics, Melville, New York, 2004.

Forward, Robert, *Future Magic*, First Avon Books Printing, June 1988.

Forward, Robert, *Indistinguishable from Magic*, Baen Pub., Riverdale, New York,1995.

Forward, R. L., *Alternate Propulsion Energy Sources Final Report, 3 March 1983 to 21 September 1983,* AFRPL TR-83-067 December 1983.

Forward, R. L, *Advanced Space Propulsion Study Final Report, 1 May 1986 to 30 June 1987*, AFRPL TR-877-070, October 1987.

Forward, Robert L., "Tether Transport from LEO to the Lunar Surface," AIAA Paper 91-2322, June 1991.

Forward, R. L, *Antiproton Annihilation Propulsion Final Report 1 April 1984 to 31 January 1985*, AFRPL TR-85-034, September 1985.

Forward R. and Davis, J., *Mirror Matter*, Wiley 1988.

Goff, Allan, "Relativisticaly Consistent Faster-than-light (FTL) Communication Using Self-Referential Quantum States," in these *Proceedings of Space Technology and Applications International Forum (STAIF-2004)*, edited by M. S. EL-Genk, American Institute of Physics, Melville, New York, 2004.

Haisch B., A. Rueda, L. J. Nickisch, and J. Mollere, "Update on an Electromagnetic Basis for Inertia, Gravitation, the Principle of Equivalence, Spin and Particle Mass Ratios," in *Proceedings of Space Technology and Applications International Forum (STAIF-2003)*, edited by M.S. El-Genk, American Institute of Physics, Melville, NY, 2003, AIP CP- 654, p. 922-931.

Hoyt, R.P. and Forward, R.L., *LEO-Lunar Tether Transport System Study, Tethers Unlimited Final Report on Subcontract S06-34444 on NASA Grant P3776-5-96 to the Smithsonian Astrophysical Observatory,* TUI, April 1997a.

Hoyt, R.P., "LEO-Lunar Tether Transport System," AIAA Paper 97-2794, 33rd Joint Propulsion Conference, Seattle, WA, 1997b.

Hoyt, R.P., "Tether System for Exchanging Payloads Between the International Space Station and the Lunar Surface," 1997 Tether Technical Interchange Meeting, Huntsville AL, Sept. 10-11, 1997c.

Hoyt, R.P. and Forward, R.L., "Tether Transport from Sub-Earth-Orbit to the Moon... And Back!" 1997 International Space Development Conference, Orlando FL, May 1997.

Levi, Barbara G., "Magnetic Forces Need Not Apply: Bose-Einstein Condensates Can Be Made in an Optical Trap," *Physics Today*, 34:7, p.20, July 2001.

Lewis, R. A., Newton, R., Smith, G. A., and Toothacker, "An Antiproton Catalyst for Inertial Confinement Fusion Propulsion," AIAA 90-2760, 26th Joint Propulsion Conference, Orlando, FL, July 16-18, 1990.

Martin, James, "A Scintillation Counter System Design To Detect Antiproton Annihilation using the High Performance Antiproton Trap (HiPAT)," in these *Proceedings of Space Technology and Applications International Forum (STAIF-2004)*, edited by M. S. EL-Genk, American Institute of Physics, Melville, New York, 2004.

Li, N. and D. G. Torr, "Effects of a Gravitomagnetic Field on Pure Superconductors," *Phys. Rev. D,* 43, 457ff,1990.

Li, N. and D. G. Torr, "Gravitational effects on the magnetic attenuation of superconductors," *Phys. Rev. B*, 46, 5489, 1992.

Li, N. and D. G. Torr, "Gravito-Electric Coupling Via Superconductivity," *Found. Phys. Lett.*, 6, p. 371, 1993.

Markopoulou, Fotini, "Planck-scale models of the Universe," *ArXiv:gr-gc/0210086* 2 7, Nov. 2002.

Moravec, Hans, "A Non-Synchronous Orbital Skyhook," *Journal of Astronautical Science*, 25:4, 307-322 Oct-Dec 1977.

Nordley, Gerald D. and Forward, Robert L., "Mars-Earth Rapid Interplanetary Tether Transport," *Journal of Propulsion and Power,* 17:3, 2001.

Nordley, Gerald D., "Interstellar Probes Propelled by Self-steering Momentum Transfer Particles," IAA-01-IAA.4.1.05, 52nd International Astronautical Congress, Toulouse, France, 1-5 Oct 2001.

Nordley, Gerald, "System Issues in Antimatter Energy Conversion," *Space Nuclear Power Systems, Vol.10*, Orbit Books, Malabar FL, pp 121-130, 1992.

Ng, Y. Jack, "Selected topics in Planck-scale physics," *ArXiv:gr-qc/0305019* 2, 15, May 2003.

Peng H. and D. G. Torr, "The Electric Field Induced by a Gravitational Wave in a Superconductor: A Principle for a New Gravitational Antenna," *Gen. Rel. and Grav*. 22, 53, 1990.

Peng, H., D. G. Torr, E. K. Hu, and B. Peng, "Electrodynamics of moving superconductors and superconductors under the influence of external forces," *Phys. Rev. B* 43, 2700, 1991.

Podkletnov E. and R. Niemen, "A Possibility of Gravitational Force Shielding by Bulk YBa2Cu3O7-X Superconductor," *Physica C*, 203 441-444, 1992.

Podkletnov E., "Weak Gravitation Shielding Properties of Composite Bulk Yba2cu3o7-X Superconductor Below 70K Under E.M. Field," *AsXiv: cond-mat/9701074* 3, 16, (Accepted in Physica C, but not yet published.) Sept. 1997.

Portilla, Miguel, "Test of the Generation of High-Frequency Gravitational Waves by Irradiating a Multidielectric Film" in these *Proceedings of Space Technology and Applications International Forum (STAIF-2004)*, edited by M. S. EL-Genk, American Institute of Physics, Melville, New York, 2004.

Ross, D.K. "The London equations for superconductors in a gravitational field," J. *Phys. A*, 16, 1331 (1983).

Smolin, Lee, *"Three Roads to Quantum Gravity: A New Understanding of Space, Time and the Universe,"* Weidenfeld & Nicolson General, Orion Publishing Co, December 2000.

Stern, Martin O., *Advanced Propulsion for LEO-Moon Transport,* NASA CR-17084, June 1988.

Vargas, Jose, "Is Electromagnetic Gravity Control Possible?" in these *Proceedings of Space Technology and Applications International Forum (STAIF-2004)*, edited by M. S. EL-Genk, American Institute of Physics, Melville, New York, 2004.

Yu et al., "Strength and Breaking Mechanisms of Multiwalled Carbon Nanotubes," *Science* 287, 637-640, 2000.