AL-TR-90-030 AD:

(2)

Final Report
for the period
30 Jul 1987 to
30 Apr 1990

21st Century Space Propulsion Study

October 1990

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F04611-87-C-0029

8181

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Prepared for the: **Astronautics Laboratory (AFSC)**
Air Force Space Technology Center
Space Systems Division
Air Force Systems Command
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FOREWORD

This final report was submitted by Forward Unlimited, Malibu CA on completion of contract F04611-87-C-0029 with the Astronautics Laboratory (AFSC), Edwards AFB CA. AL Project Manager was Dr Franklin B. Mead, Jr..

This report has been reviewed and is approved for release and distribution in accordance with the distribution statement on the cover and on the DD Form 1473.

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release: Distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AL-TR-90-030
6a NAME OF PERFORMING ORGANIZATION Forward Unlimited 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Astronautics Laboratory (AFSC)
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 2783 Malibu, CA 90265-7783 USA	7b. ADDRESS (City, State, and ZIP Code) AL/LSVF Edwards AFB, CA 93523-5000
8a NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F04611-87-C-0029
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 6230F; PROJECT NO. 3058; TASK NO. 00; WORK UNIT ACCESSION NO. 7E

11. TITLE (Include Security Classification)
21st Century Space Propulsion Study (U)

12. PERSONAL AUTHOR(S)
Forward, Robert L.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 87JUL30 TO 90APR30	9010	75

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP
16	04	

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
antimatter, solar sails, tethers, cable catapult, space warps, negative matter, microspacecraft, statite, levitated orbits, solar photon thrustor

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The contract objective was to monitor the research at the forefront of physics and engineering to discover new space propulsion concepts. The major topics covered were antiproton annihilation propulsion, solar sails, space tethers, microspacecraft, and unconventional propulsion concepts. Nine papers were published on: (1) using light pressure to levitate a communication satellite poleward from its position on the equatorial geosynchronous orbit; (2) a "polesitter" spacecraft that uses light pressure to hover over the polar regions of the earth; (3) a complete analysis of all the forces on a non-ideal "grey" solar sail; (4) a new solar sail design with better performance than a standard solar sail; (5) a new tether transportation system called the "cable catapult"; (6) a thorough analysis of propulsion using negative matter; (7) a review of space warps; and (8,9) two reviews of advanced space propulsion. Also published were issues #8 through #18 of the Mirror Matter Newsletter on the science and technology of stored antimatter. Five other reports are included as appendices.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
Dr. Franklin B. Mead, Jr.	(805) 275-5540	AL/LSVF

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED

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INTRODUCTION AND SUMMARY

The objective of the 21st Century Space Propulsion Study was to identify new space propulsion concepts that would add to Air Force capabilities in space on into the 21st Century. Completely new and revolutionary concepts were desired, rather than extensions of proven propulsion techniques.

The study initially focused on three major thrusts. The first was to continue to study the feasibility of antiproton annihilation propulsion, the promising new space propulsion concept identified by the Principal Investigator (PI) in a previous contract carried out for the Astronautics Laboratory (AL). The second was to continue to monitor experimental research at the forefront of engineering and physics to discover new technology and novel scientific phenomena that might have application to space propulsion. The third was to seek out anomalous areas of understanding in well-known and less-known theories of physics. These anomalous areas were then to be studied in an attempt to find breakthroughs in physical understanding that could lead to major advances in science and technology, especially those breakthroughs that could lead to revolutionary advances in space propulsion.

The 33 month study effort was very productive. Major advances were made in the field of solar sails, with four papers and two patent applications. Significant advances were made in the field of tether propulsion, with a paper, a report, and a patent application. A number of more exotic concepts were studied, with most of the concepts being found invalid or unproven, but even here, some progress was made, resulting in three papers and three reports. In all, ten different concepts were developed to the point that scientific papers were prepared for presentation at professional meetings and/or publication in technical journals. In addition, five reports were prepared for use by AL and other government agencies in formulating future space technology policy.

Three of the concepts developed on the contract were deemed novel enough that patent disclosures were prepared and filed with the Air Force Staff Judge Advocate. These are discussed in the section on Patents and New Technology.

In addition to the nearly dozen studies that came to a successful conclusion, there were other studies that were undertaken, but after a time it was realized that further effort on those areas would be unproductive and those studies were dropped. Most of the purported "reactionless space drives" and "antigravity" machines that the PI was asked to evaluate fall into that category.

A major contractually required effort on the study was to advance the cause of antiproton annihilation technology. All through the contract period, the PI continued to edit the Mirror Matter Newsletter, an informative newsletter on antimatter science and technology distributed to over 800 scientists, engineers, and libraries. Ten issues, each the length of a scientific paper, and totaling 80,000 words--the length of a standard novel--were published during the study effort.

ANTIPROTON ANNIHILATION PROPULSION

Antimatter propulsion is no longer science fiction. Antimatter is already being generated, captured, cooled, and stored at a number of particle physics laboratories around the world, albeit in small quantities. When an antimatter particle is allowed to contact a normal matter particle, all of the mass in both particles is released as energy, making it the most energetic fuel known. The most effective particle of antimatter for propulsion is the antiproton rather than the antielectron. To make a compact fuel for easy storage, the antiproton should be combined with the antielectron to make frozen antihydrogen. In antimatter propulsion, milligrams of antihydrogen are used to heat tons of reaction fluid (water or liquid normal hydrogen) to high temperatures. The hot reaction fluid is then exhausted from a nozzle to produce high thrust at high specific impulse.

In three prior contracts[1-3] for AL, the PI of this contract carried out studies of the physical, technological, and economic feasibility of making, storing, and using antiprotons for space propulsion. The conclusion of the studies were that antiproton propulsion is feasible, but expensive. Because the low mass of the antimatter fuel more than compensates for its high price, comparative mission studies show that antimatter fuel can be cost effective in space, where even normal chemical fuel is expensive because its mass must be lifted into orbit before it can be used. Because the mass ratio of an antimatter powered spacecraft never exceeds 5:1, no matter what the efficiency of utilization of antimatter, and no matter how much ΔV the mission requires, antiproton annihilation propulsion is mission enabling, in that it allows mission to be performed that cannot be performed by any other propulsion system.

The primary thrust called out in the contract for this study effort was to continue to advance the concept of advanced space propulsion using the annihilation energy from stored antiprotons. To carry out this task the PI was to encourage, monitor, and report on experimental and theoretical antimatter research around the world. He was to identify those scientific and technological issues that were important to determining the feasibility of antiproton annihilation propulsion, but were not being adequately addressed. He was then to propose investigations to address those issues, as well as the best researchers to carry out those investigations.

A specific subtask called out in the contract was to continue to edit and distribute the Mirror Matter Newsletter. This is a free, informative newsletter containing news and bibliographic information about the science and technology of stored antimatter. Through the newsletter and by personal contact, the PI was to

introduce new investigators to the field, inform them of relevant work by others, assist them in making contact with potential sources of research support, and otherwise improve their research effectiveness. A partial listing of those activities follows:

During 6-13 September 1987, the PI attended the IV LEAR Antiproton Physics Workshop in Switzerland. There were 150 attendees, nearly all of them European, plus three Soviet scientists. The Workshop organizers requested that the PI give an informal short talk on Antiproton Annihilation Propulsion based on cleared material in a previous contract report.[2] The talk was followed by a strenuous question and answer session which lasted two hours. A number of skeptics were convinced by the talk that they could no longer ignore the subject and eighteen attendees asked to have further information sent to them. A few skeptics allowed their anti-military and/or anti-American emotions to cloud their scientific objectivity and became abusive. The results of the meeting were reported to interested US scientists through the next issue of the Mirror Matter Newsletter.

During 4-9 October 1987, the PI attended the Second Antiproton Science and Technology Workshop at RAND Corporation in Santa Monica, California, to participate in the Antiproton Production and Collection Working Group. Two papers were contributed for the proceedings, "Production of Heavy Antinuclei: Review of Experimental Results" and "Antimatter Science and Technology Bibliography". Both papers were appendices in a cleared final report[3] to a previous AL contract.

A survey of the presentations at the Workshop found no "showstoppers" that would prevent the production and storage of macroscopic amounts of antimatter. Indeed, the optimism expressed in a number of the papers by experts in particle physics engineering seemed to indicate that with sufficient R&D funding, most of the obvious problems were solvable. The three problem areas that needed the most effort were the high rate cooling of large numbers of antiprotons, the high rate conversion of antihydrogen atomic gas into a condensed molecular solid, and the design of antimatter engines with acceptable prompt and delayed radiation levels. The meeting results were reported to interested US scientists in the next issue of the Mirror Matter Newsletter.

From 10-17 October 1987, the PI attended the 38th Congress of the International Astronautical Federation in Brighton, England where he was Co-Chairman of the Interstellar Space Exploration Symposium. During the meeting, the PI added substantive comments to two papers on antiproton propulsion given by others and collected a number of new readers for the Mirror Matter Newsletter. One paper, a new propulsion scheme proposed by Subotowicz of Czechoslovakia based on the "pionization" of matter in heavy ion collisions was found by the PI to be seriously in error in its basic particle physics assumptions.

From 29 November to 2 December 1987, the PI attended ANTIMATTER '87, a Symposium on the Production and Investigation of Atomic Antimatter held in Karlsruhe, Germany. There were over 70 scientists attending, most of them from European countries. Thirty-five papers were presented on subjects ranging from positron, antiproton, and heavier antinuclei production, three methods for the production of antihydrogen atoms from antiprotons, laser cooling and neutral antiatom manipulation, and antimatter trapping concepts including two new trap concepts. These results were reported to interested US scientists in the following issue of the Mirror Matter Newsletter.

On 9 January 1988, the PI presented a two-hour tutorial lecture on Antiproton Annihilation Propulsion as part of a Nuclear Propulsion Short Course held prior to the 5th Space Nuclear Propulsion Workshop in Albuquerque, New Mexico.

In December 1988 a special issue of the Mirror Matter Newsletter was written and distributed to insure that the AL initiated SBIR announcement for AF 89-192 "Technology for Storage, Handling, and Use of Antimatter", got the widest possible distribution to those US scientists with ar active interest in research on antimatter.

From 13-15 February 1989, the PI attended the Aerospace Engineering Conference and Show in Los Angeles, California, where he chaired a session he had organized on Antiproton Power and Propulsion. The session had papers by Col. James Ross Nunn, then Commander of the Air Force Astronautics Laboratory; Dr. Bruno Augenstein, RAND Corporation; Dr. Giovanni Vulpetti from Telespazio in Rome, Italy; Mr. V.E. Haloulakos of McDonnell-Douglas; and the PI. The PI repeated his paper at the evening "instant replay" session. The upcoming conference session was announced to interested US researchers in the prior issue of the Mirror Matter Newsletter.

From 9-11 May 1989, the PI attended the Workshop on Antiproton Technology held at Brookhaven National Laboratory in Upton, New York and contributed to the discussions. The results of the workshop were reported to interested US scientists in the next issue of the Mirror Matter Newsletter.

All through the contract period, the PI wrote, published, and distributed the Mirror Matter Newsletter, an informative newsletter on antimatter science and technology distributed free to over 800 scientists, engineers, and libraries, most of them in the United States. Distributed about once every three months, each issue contained 10-14 pages, single spaced, of news and bibliographic information about antimatter science and technology. The intent of the newsletter was to act as an information source on antimatter until the typical formal and informal channels of communication between antimatter scientists and engineers had developed. As a result of interactions through the newsletter and

the various workshops over the past years, those standard communication channels have now developed. There is an International Low Energy Antimatter Conference now scheduled for every other year, and Antimatter Users Workshops planned annually in the US. As a result, the newsletter was terminated with the 18th issue dated May 1990. Copies of issues 1 through 7 can be found in Appendix F of a previous contract report.[3] A complete set of back issues (220 pages) can be obtained from: Forward Unlimited, P.O. Box 2783, Malibu, CA 90265-7783 USA, for the cost of reproduction and mailing (about $25.00).

SOLAR SAILS

Solar sails are lightweight sheets of reflective material attached to a spacecraft that use the light pressure force from solar photons to produce propulsive thrust. The major advantage of solar sails as a propulsion system is that the spacecraft does not need to carry either an energy source or reaction mass in order to obtain propulsion, and as a result never runs out of fuel. Over the decades, a good deal of effort has gone into the design of solar sails, and many reports have been written and published, but as yet, no solar sail has flown. Part of the reason is that solar sail technology is unproven and therefore a risky option for mission planners. Another reason is that solar sails must be deployed above about 1000 kilometers altitude, because below that altitude the atmospheric drag force on the sail exceeds the solar light pressure force.

If solar sails could be made practical and launchable at Space Shuttle altitudes, then they could be of significant service to future Air Force needs. Solar sails could move military space assets from LEO to GEO, from a point in GEO over one country to another point in GEO over another country, or from any place in space to any other place, as often as desired, without the expense of launching propellant into space. Solar Sails could also allow a military space vehicle to continuously "hover" over the polar regions of the Earth for surveillance, weather, communication, and weapons purposes.

GREY SOLAR SAILS

During the study effort, the PI contributed significantly to both the basic science and the technology applications of solar sails. During his research on the subject of solar sails, he found that there was no document that accurately described the physical properties of a non-ideal "grey" solar sail. As a result, he wrote the definitive paper on the subject, a lengthy analysis of "Grey Solar Sails", that was published in the Journal of the Astronautical Sciences.[4]

SOLAR PHOTON THRUSTER

A major contribution of the PI to the technology of solar sails was the invention of a new sail structure called the Solar Photon Thruster. A more detailed discussion of the Solar Photon Thruster can be found in the Patents and New Technology section starting on page 21. A technical paper describing the concept has been accepted for publication in the Journal of Spacecraft and Rockets.[5]

As is shown in Figure 1 on page 22, the Solar Photon Thruster is a two-sail structure in a Cassegrain configuration that has improved performance over a standard solar sail of the same area because it separates the function of collecting the solar photons from the function of reflecting the solar photons. The collector sail on a Solar Photon Thruster is a large reflecting surface similar in size and mass per unit area to that of a standard flat solar sail. The collector sail always faces the Sun so as to present the maximum area for collection of sunlight. The collector is also a curved light concentrator. The concentrated sunlight is sent to a reflecting sail of much smaller area and mass, which redirects the light in the proper direction to produce the desired thrust direction.

While a flat solar sail suffers in effective light collection area when it is tilted in order to direct the light pressure force in a direction other than directly away from the sun, the Solar Photon Thruster always has the maximum collecting area facing the sun, no matter what the desired thrust direction.

A major advantage of the Solar Photon Thruster over the prior art solar sails is that it can be launched at Space Shuttle altitudes if placed in a polar terminator orbit. In this orientation, the spacecraft stays continuously in the sunlight so the large collecting sail is always facing the sun collecting the maximum amount of sunlight for maximum thrust, while at the same time traveling edge-on to the atmosphere to produce minimum drag. The reflecting sail is then adjusted to give maximum thrust along the orbit, rapidly raising the altitude. Within a few days the Solar Photon Thruster will be above 1000 km altitude and can be switched to any desired orbital trajectory optimum for the mission.

LIGHT-LEVITATED GEOSTATIONARY ORBITS

During the study, the PI found new methods to utilize spacecraft with solar sails, whether the sails are standard flat sails or the new improved Solar Photon Thruster. For example, solar sails can be used to "levitate" a communication satellite in equatorial geostationary orbit to a new orbit that is north or south of the equatorial orbit, yet is still geostationary to a point on the ground. This concept is described further in a paper "Light-Levitated Geosynchronous Cylindrical Orbits: Correction and Expansion" that was accepted for publication in the Journal of the Astronautical Sciences.[6]

STATITE: A NON-ORBITING SPACECRAFT

During the study effort, the PI also invented a new class of spacecraft, called a statite. All spacecraft flown to date are satellites of the Earth or some other gravitating body. A satellite of Earth is defined as a spacecraft that is in orbit about a point that is the common center of mass of the spacecraft and the Earth. In contrast, the statite is a spacecraft that does not orbit. Since it does not orbit, it is not a satellite. The generic name of "statite" has been given to these types of spacecraft since they remain static or stationary with respect to the common center of the spacecraft and the Earth. The statite remains stationary by using light pressure force on a solar sail to exactly counteract the attractive gravitational force of the Earth. A patent was filed on the concept which is discussed further in the section on Patents and New Technology. A paper discussing the concept has been accepted for publication in the Journal of Spacecraft and Rockets.[7]

In most applications, the statite is placed at a point above the dark side of the Earth as shown in Figure 2 on page 24, while the Earth spins beneath it. From the viewpoint of an observer on the rotating Earth, the statite rotates around the pole once every 24 hours. Thus, ground stations for communication with these systems must have their antennas on a polar mount with a 24 hour clock drive. Since the distance between the ground station and the statite does not change significantly in magnitude, and the doppler shifts are very low, the electronics needed for these versions of the system of the invention are nearly as simple as those at the fixed position ground stations used for the equatorial geostationary orbit satellites.

A typical distance of a statite from the center of the Earth will be 30 to 100 Earth radii. (For reference, geostationary orbit is at 6.6 Earth radii and the Moon is at 63 Earth radii.) Thus, one unavoidable disadvantage of the statite system is that the communication link round-trip delay time is a number of seconds, making it more suitable for surveillance, weather mapping, data links, and faxes than two-way telephone conversations.

At distances of about 250 earth radii, it is possible for a statite to be placed so that it "hovers" over the north or south poles of the Earth 365 days a year--even during the half of the year when the polar region being observed is in the sunlight. Details of the exact altitudes and conditions for different sail designs can be found in the paper.[7]

Because a statite is not orbiting and has the ability to hover over the polar regions, it can accomplish a number of military unique missions that could enhance the Air Force's future posture in space. A polesitter statite over the poles could provide continuous global weather maps of the regions around the poles,

where all the weather starts. True hemisphere-wide communications to the north or south hemispheres could be accomplished with a single satellite. A polesitter statite could also serve as an early warning of over-the-pole ballistic missile attacks. Placing statites off the polar axis at fixed latitudes over the dark side of the Earth would result in lower statite altitudes, and therefore shorter round-trip communication delay times, and higher resolution for infrared and microwave surveillance.

Since a statite is not orbiting, anything dropped from it does not stay in orbit, but falls straight down. A statite carrying a load of "intelligent crowbars" would be a unique weapon system that could surgically take out individual buildings, individual vehicles, even perhaps individual people by direct hit-to-kill impact from a terminal-guided atmospheric penetrator.

A two kilogram "intelligent crowbar" dropped from a statite hovering over the Earth at 30 Earth radii would reach the upper atmosphere of Earth in 17 hours. It would be traveling at 9 km/s, or nearly escape velocity. If the incident that instigated the dropping of the crowbar were over, the crowbar could be fragmented and burned up in the upper atmosphere like a meteor. If the danger persisted, the crowbar would pass through the 150 km of atmosphere in 15-20 seconds, striking the surface with an energy of 80 MJ (the equivalent of 20 kg of high explosive). This energy could be deposited over an area by fragmenting the crowbar at the proper altitude, or alternatively, the crowbar could penetrate protective buildings or shallow bunkers to reach its point target.

When used in limited warfare, such a weapon could reach a target anywhere on the globe in less than a day without risking US manpower or assets, and destroy that target while causing minimum ancillary damage. It would be an ideal weapon for dealing with terrorists, tinpot dictators, and drug runners (by direct hit) and their plantations (by air bursts).

TETHERS

Tethers are long cables in space that are used to couple spacecraft to each other, to other masses, and to force fields in space. The tether coupling allows the transfer of energy and momentum from one object to another, and so are a form of space propulsion.

In the early 1990s there will be two shuttle experiments to demonstrate the engineering feasibility of the tether concept. NASA is funding Martin Marietta to build the tether (2.5 mm diameter and 100 km long) and the deployment mechanism, while Italy is building the spacecraft that will fly at the end of the tether. The first experiment, scheduled for 1991, will deploy the spacecraft upward from the Shuttle on a conducting tether cable to demonstrate power generation from the motion of the conducting cable through the Earth's magnetic field. By pumping current through the cable, thrust would be generated by the "push" of the cable against the Earth's magnetic field. The second flight will deploy an atmospheric research spacecraft downward, where it will fly through the upper atmosphere, too low for spacecraft and too high for aircraft. The tether connection to the Shuttle spacecraft provides the propulsion needed to overcome the drag.

Other tether experiments on unmanned spacecraft are underway to study the dynamics of reeling tethers in and out, and releasing payloads from the end of librating or rotating tethers. The field of space tethers is a promising evolving technology and some versions have application to future Air Force needs. During the contract effort, the PI continually monitored this developing field and was able to make some contributions.

TETHER BOOTSTRAP PROPULSION

In March 1989, the Principal Investigator attended a Workshop on Advanced Propulsion at NASA/Lewis Research Center. While there he met a NASA engineer, Geoffrey R. Landis, that had come up with a new concept for using tethers for spacecraft propulsion that did not involve the use of expendable propellant. At the time, Landis was proposing to use the concept to shift the positions of spacecraft along geosynchronous orbit. This application alone is of significant military value, since it can allow military assets to be moved to new positions at will, defeating enemy countermeasures.

The PI realized that the concept was more general, and could be used to not only shift positions at constant altitude, but could also be used to change altitude. Although energy was required, no propellant was needed. The PI encouraged Landis to expand his

original internal memo into an official NASA Memorandum[8] covering the broader aspects of his concept, thus bringing the concept to the attention of the propulsion and tether communities. The basic concept of Geoffrey R. Landis is that if two halves of a spacecraft (or a spacecraft and its expended booster) are extended on a long tether, the center-of-mass of the extended system shifts slightly downward from the original center-of-mass and the orbital period decreases. This shift in the center-of-mass occurs because the Earth's gravity force causes an acceleration on the masses that varies as $1/r^2$, while the counteracting centrifugal force due to orbital motion causes an acceleration that varies as r. For very long tethers, the two forces no longer exactly cancel at the two ends and there is a residual, second order, force which must be balanced by a shift in the center of mass. When the tether is pulled in again, the center-of-mass of the combined system raises upward. By alternately extending and contracting the tether at proper points in the orbit, the tether can be used to "pump" an initially circular orbit into a highly elliptical orbit, and perhaps to escape.

Unlike other tether propulsion concepts in the literature, where one mass (the payload) is raised in orbit while another mass (the counterweight) is lowered in orbit, the technique developed by Landis allows the center-of-mass of the entire system to be raised from a low circular orbit into a high elliptical orbit--conceptually into an escape orbit from Earth--without the use of rockets or reaction mass. Energy is required, which can be supplied from an onboard power supply, but no reaction mass is needed, and if the Earth-to-LEO booster is used as a counterweight for the payload mass, the only weight penalty is the mass of the tether (compared with the weight penalty of a LEO-GEO booster rocket). A report discussing the new concept was prepared and submitted to the Contract Technical Monitor in May 1989 (See Appendix A.)

Most important from the standpoint of possible Air Force applications of the technique, Landis estimates that it would take only 6.5 days to go from a circular LEO of 0.75 Earth radii (about 5000 km) to a highly elliptical transfer orbit that goes up to GEO. There, a rocket burn could circularize the orbit, or possibly the expended booster (which is also transferred along with the payload) can be tossed away in the right direction to obtain the angular momentum necessary to achieve circular GEO.

Since this new propulsion concept seems to be able to provide useful, reasonably rapid propulsion near the Earth without the use of rockets and only the use of a power supply, which many Air Force payloads have anyway, it is recommended that someone in the Advanced Propulsion Branch of the Astronautics Laboratory follow and encourage the work of Landis, and perhaps carry out parallel studies on its feasibility for and applicability to present and future Air Force space missions.

CABLE CATAPULT

During the study effort, the Principal Investigator also found a new way to use tethers for propulsion, called the Cable Catapult. A paper describing the Cable Catapult concept was prepared and submitted to the Journal of Spacecraft and Rockets.[9]

In addition to the Landis Tether Bootstrap technique described in the previous section, there were two other prior tether propulsion techniques known. One prior technique involved stretching the tether between two masses at different orbital altitudes. When the tether was cut, one mass would go up in orbital altitude 7 times the tether length, while the other one would go down 7 times the tether length (usually deorbiting in the process). The other prior technique involved librating or rotating the tether with a payload on one end. When the payload is traveling in the right direction at the maximum tip speed the tether could withstand, the payload would be released to travel on its way.

The maximum payload velocity of the rotating tether propulsion system is roughly three times the "characteristic velocity" of the material in the cable. The characteristic velocity is the square root of the design tensile strength of the tether material divided by the density of the material. For most tether materials it is 1 km/s. Since the mass of a rotating tether rises as the exponential of the square of the payload velocity divided by the characteristic velocity, as a practical matter the required mass ratio becomes too high once the payload velocity exceeds three times the characteristic velocity, or 3 km/s for a tether made of 1 km/s material.

In the Cable Catapult invented by the PI, instead of rotating the tether, the tether or cable is stretched in a straight line along the desired direction of travel as shown in Figure 3 on page 27. Then, a linear motor capable of traveling along the tether is used to accelerate a payload up to speed. An analysis of the required mass ratio of this tether propulsion system shows that the mass of the tether goes only as the square of the payload velocity divided by the characteristic velocity, not the exponential of the square. Because of this, a Cable Catapult can launch a payload at ten times the velocity of a rotating tether launcher of the same mass. This means payload velocities of 30 km/s for a 1 km/s tether, or 100 km/s for futuristic tether materials. Payload speeds this high can revolutionize travel in the solar system. Another major advantage of the Cable Catapult is that with proper design it can be made energy conservative. That is, energy from incoming payloads can be stored and used to launch outgoing payloads. This is in contrast to rocket systems, where a mass ratio of fuel must be expended at each launch and deceleration. If they can be demonstrated to be technologically feasible, such Cable Catapult systems could drastically cut the costs of mounting the President's Moon/Mars Space Exploration Initiative.

MICROSPACECRAFT

The PI has always been an advocate of designing minimum mass spacecraft for difficult missions in order to minimize the propulsion difficulty and enable the mission to be funded. In prior contracts[1,3] he has envisioned conceptual designs for spacecraft weighing a few grams.[10,11]

During 10-17 October 1987, the PI attended the 38th Congress of the International Astronautical Federation in Brighton, England where he was Co-chairman of the Interstellar Space Exploration Symposium. One of the papers, given by Bruno Augenstein of RAND Corporation, expanded on a previous paper[11] by the PI to come up with a system that could communicate with extraterrestrial intelligent beings, not by radio signals, but by large numbers of small "calling card" microspacecraft unmanned probes that would be sent to the target star systems by beamed laser propulsion. Upon arrival their emissions would be detected by the extraterrestrial beings, who could then pick them up and read the microengraved messages on the surface.

On 6-7 July 1988 the PI attended the Microspacecraft for Space Science Workshop at the Jet Propulsion Laboratory as a member of a panel of invited science and technology experts which included Bruce Murray and Freeman Dyson. As part of his duties as a panel member, he prepared a white paper summarizing the results of the workshop and his recommendations for future work (See Appendix B).

HIGH RISK, HIGH PAYOFF STUDIES

A unique aspect of this study effort was the requirement in the PRDA soliciting proposals for: "An effort to seek out and evaluate the anomalous areas in the older, well established theories of physics and the newer, less accepted theories of physics, define the implications of the breakthrough physics found in the theories, and propose experimental and theoretical efforts that may lead to revolutionary advances in science and technology."

As a result of this requirement, a small portion of the contract study time was spent on subjects (reactionless drives, antigravity, space warps, etc.) that would normally be forbidden topics in a government contract. Since the PI has a background in physics, he was able to actually make some progress on some of the topics--enough progress that two papers written on these taboo subjects were published in peer-reviewed scientific journals after having gone through the skeptical scrutiny of the journal's editors and referees.

NEGATIVE MATTER PROPULSION

Negative matter is a hypothetical form of matter with negative gravitational, inertial, and rest mass. Negative matter is not antimatter, which as far as we know has positive gravitational, inertial, and rest mass. Negative matter should not exist, for if it did, it would be possible to build propulsion systems that would produce an unlimited amount of unidirectional acceleration without the expenditure of energy or reaction mass, and free energy machines that would provide unlimited amounts of mechanical energy.

The PI studied the concept of negative matter in extensive detail and found that despite its amazing propulsion properties, the concept of negative matter seems to violate no law of physics. A system involving equal amounts of positive and negative matter can produce a nearly unlimited amount of energy and momentum in the positive matter object, because the negative matter object is gaining an equal but opposite amount of negative energy and momentum at the same time.

A lengthy (70 page) paper discussing these nearly unbelievable study results was prepared. Copies of the papers plus personal letters were sent to some twenty renowned scientists who had previously written papers on negative matter, or who were expert in the field of gravitation, astronomy, or exotic particle physics to insure that the scientific background for this unconventional paper was as solid as possible. No objection were made to the paper as written. A shortened version of the paper was published

in the January/February 1990 issue of the AIAA Journal of Propulsion and Power.[12] At the end of the paper, the PI makes some suggestions for further research into this very exotic, high risk, high payoff field.

SPACE WARPS

Space warps are hypothetical tunnels in space that allow travel through the tunnel from one point in space to another point in space, thus avoiding having to travel over the normal space between the two points. If the distance through the space warp tunnel can be made shorter than the distance through normal space, then the journey is shortened. During a portion of the study effort the PI reviewed the extensive physics literature in this field and wrote a review paper which was published in the November 1989 issue of the Journal of the British Interplanetary Society[11].

In the paper the PI brings out the fact that in the Einstein theory of gravity, the General Theory of Relativity, warpage of space can not only be caused by dense masses, such as black holes, but also by charge and angular momentum. If the Einstein equations could be applied to an elementary particle like the electron (they cannot, because the Einstein equations are not valid in the quantum domain), then the relative space warpage caused by the mass of an electron is only 10^{-40}, while the space warpage caused by the charge of an electron is 1/137, and the space warpage caused by the spin of an electron is 1/4.

The paper ends by recommending that theoretical and experimental research on the space warping effects of highly charged, rapidly spinning heavy nuclei should be carried out. Such research could potentially lead to concepts for small space warps that do not involve black holes or stellar quantities of dense matter.

NEUTRINO CONTROL

It is a canonical saying of neutrino physics that a neutrino can pass through lightyears of lead without being stopped. There have been experiments reported in the scientific literature, however, that seem to indicate that low energy neutrinos are coherently scattered by just a few centimeters thickness of crystalline material with a high stiffness and extremely high crystalline order. Although this coherent neutrino scattering effect would not lead to a new form of propulsion, it could lead to a highly sensitive neutrino "telescope" that could find hidden nuclear warheads at short ranges and would allow the detection of submerged nuclear submarines at long ranges. It could also conceivably lead to new communication systems using neutrinos instead of electromagnetic radiation.

A portion of the contract study effort was spent talking to the three experimentalists involved in the various coherent neutrino scattering experiments and evaluating their results. A report to the Contract Technical Monitor on the results of the evaluation can be found in Appendix C. In the report the PI makes a number of recommendations for further research to prove or disprove the purported effect.

REACTIONLESS DRIVES

During the study, one of the unenviable tasks of the PI was to evaluate the "reactionless drives" that were brought to his attention. A number of these were evaluated, with (expectedly but unfortunately) no positive results.

The initially most promising reactionless drive was the EZKL Propulsion System invented by Mr. Brandson Roy Thornson of 118 Emerald Grove Drive, Winnipeg, Manitoba, R3J 1H2, Canada. According to the inventor, the device had purportedly passed the "pendulum test".

In the pendulum test, the reactionless drive device under test is hung by a wire from above. If it can produce reactionless drive forces, then the drive will move to one side and stay there, the angle of the wire indicating the relative reactionless drive force compared to the Earth's gravity force. This test was devised in an attempt to eliminate rectified vibrational forces that in the past have produced unidirectional motion in previous "reactionless drives" that moved a cart across the floor or a boat across water.

The EZKL device involved a mechanical apparatus with various motors, cams, gears, and electromagnetic latches that produced oscillating forces on the case surrounding the apparatus. The case of the apparatus not only oscillated linearly with respect to the center of mass, but oscillated in angle around the center of mass. The apparatus was designed so the force in one direction is short in time and hard, while the force in the opposite direction is longer in time and soft.

It was Mr. Thornson's contention that the averaged oscillating forces in one direction exceeded the averaged oscillating forces in the opposite direction. His evidence, as presented on a videotape of the device in action, consisted of: (1) The sensation of unidirectional force by observers holding the apparatus. (2) The unidirectional motion of the apparatus (on a styrofoam float) across a shallow tank of water. (3) The unidirectional motion of the apparatus (on wheels) across a table. (4) The average deflection offset of a light spot on the floor from the beam of a flashlight attached to the bottom of the apparatus case, while the apparatus was hung by wires from the ceiling (the pendulum test).

The videotape did not convince the PI. Concerning evidence (1): The human body is notoriously unreliable as a sensing instrument. All our senses, including the kinetic sense of our bones and muscles and reflexes, are inherently non-linear. Large forces produce a very large sensation, while small forces are hardly felt at all. It is not surprising that the volunteers felt more motion in one direction than another.

Concerning evidences (2) and (3): The PI, personally, has moved himself across the water in a canoe, and across the floor in an ordinary office chair, by merely shifting his body back and forth, rapidly in one direction and slowly in the other. Real floating objects and real wheeled objects always exhibit some sort of non-linear friction processes while operating, and are not suitable for demonstrations of net unidirectional force. That is why the pendulum test is recommended.

Concerning evidence (4): The next time the PI recommends the pendulum test, he will add that the measurement of the offset from the vertical has to be made of the center of mass of the apparatus. In Thornson's experimental setup, the flashlight creating the beam was attached firmly to the bottom of the case of the apparatus, pointing down. The beam was then directed to the floor below to create the spot that was measured. With this setup, the light spot on the floor could be deflected by three mechanisms, two of which would give spurious results.

The three mechanisms are: (a) Case offset--the motion of the case surrounding the apparatus to one side of the center of mass of the apparatus. (Something internal would have to move in the opposite direction, of course.) (b) Case rotation--the rotation of the case around the center of mass of the apparatus. (Something internal would have to rotate the opposite direction, of course.) (c) The desired measurement--the motion of the center of mass of the apparatus off from its rest point below the suspension point of the pendulum from the ceiling due to a true reactionless force generated by the device.

Suppose we have a child standing on a swing. A flashlight is fixed firmly to the bottom of the swing seat, pointing downward. Spurious mechanism (a) can be simulated by the child leaning back and pushing on the seat with his feet and holding that position. The seat would move one way and the child's body would move the other way. The flashlight, being attached to the seat and not to the center of mass of the child and the seat, would be offset to one side, giving a false reading. Spurious mechanism (b) can be simulated by the child simply raising his toes and lowering his heels. Although the center of mass of the child and the seat, and their combined center of mass, would all remain in the same place, the seat would be tilted, tilting the flashlight, deflecting the light beam to one side, and giving a false reading.

When watching the demonstration of the EZKL device on the video, the PI observed that the deflection of the light beam spot on the floor was caused by the case rotating around the center of mass of the apparatus, not by any deflection of the apparatus to one side. Thus, the pendulum test, being flawed in the design of the deflection measurement system, was not convincing evidence.

In summary, from the evidence that was seen, the EZKL Propulsion System did not pass the pendulum test, and did not demonstrate unidirectional force from a closed system.

ANTIGRAVITY

The Fifth Force is a postulated long range gravity-like repulsive force that is a function of other properties of a nucleus than mass. Since the Fifth Force is repulsive, it can be used to counteract gravity. During the contract study period, the PI monitored the scientific literature published on experiments to verify or disprove the initial experiments that seemed to indicate the existence of a fifth force. Despite some initial positive results from a measurement of the Earth's gravity up a tall television tower by the Air Force Geophysical Laboratory, and similar measurements down a bore hole in the Greenland ice cap, the present consensus is that the non-negative results are caused by subtle biases in the data collection, rather than evidence for some new force of nature. The counter-evidence is not conclusive, however, and further research in this area should be entered into with an open mind and careful attention to the possibility of subtle bias errors in instrumentation and data analysis.

In January 1988 th' PI visited Prof. James Woodward at California State University Fullerton to see his experimental demonstration of a possible electrogravity device. The apparatus was a large capacitor on a sensitive scale with a lot of shielding in an attempt to eliminate any electrostatic or electromagnetic forces. A decrease in mass of the capacitor was purported to occur during the short interval when the capacitor was charging. A working model was not available during the visit, and the data shown to the PI was extremely noisy and not convincing.

SPACE PROPULSION POLICY ASSISTANCE ACTIVITIES

Since the PI has developed a world-wide reputation as a person who is knowledgeable about nearly all the different space propulsion techniques, has no personal or corporate imposed biases for or against any advanced propulsion technique, and has an open mind to unconventional and far future propulsion concepts, he is often asked to contribute "white papers" to assist government and national aerospace organization policy makers as they try to make plans for the future. There were four such efforts. One was a list of advanced astronautics technologies prepared for the Air Force Astronautics Laboratories (See Appendix D), one was a list of potential benefits to Earth from the President's Moon/Mars Space Initiative prepared for the National Space Council (See Appendix E), one was a keynote speech to the NASA/Lewis "Vision-21: Space Travel for the Next Millennium", a symposium to look beyond conventional next-generation thinking about future directions of science and technology in astronautics and space exploration,[14] and one was a review article on advanced space propulsion for the July 1990 issue of the AIAA Aerospace America magazine.[15]

In addition, the American Institute of Aeronautics and Astronautics appointed the PI as one of the AIAA Distinguished Lecturers for the 1989-90 academic year. The AIAA pays the travel expenses of the PI to visit some of the smaller sections around the country that would otherwise have difficulty obtaining speakers. During the nine month appointment, the PI made 13 trips and presented 22 lectures on advanced propulsion concepts.

PATENTS AND NEW TECHNOLOGY

During the contract activity, a number of new space propulsion concepts were generated, discovered, or rediscovered. One of these proved to be patentable, while two should be considered "new technology" even though it would not be feasible to patent them because of economic reasons, prior art limitations on claims, or inability to reduce to commercial practice before the life of the patent expires.

The three major new concepts that were developed far enough so that patent disclosures could be prepared for submission to the Air Force Staff Advocate General were:

SOLAR PHOTON THRUSTER

A space vehicle that uses a solar sail for propulsion can be significantly improved in performance by separating the function of collecting the solar photons from the function of reflecting the solar photons. In the Solar Photon Thruster shown schematically in Figure 1, the collector is a large reflecting surface similar in size and mass per unit area to that of a solar sail. The collector faces the Sun so as to always present the maximum area for collection of sunlight. The collector is modified in structure so it is a light concentrator. The concentrated sunlight is directed to a reflecting surface of much smaller mass, which redirects the light to provide net solar photon thrust in the desired direction. To minimize undesired torques, the collecting and reflecting portions of the system can be arranged so that the net force passes through the center of mass of the total system including payload. Variation of the collector and reflector positions can produce spacecraft rotational torques if desired.

Since the collector of the sunlight in the Solar Photon Thruster is always facing the Sun no matter what the desired direction of thrust, the Solar Photon Thruster always operates in a maximum solar light power collection mode. This is in contrast to the prior art solar sail propulsion system where the collector and reflector are the same sheet of reflecting material.

In the prior art solar sail propulsion system, if the desired direction of thrust is not directly away from the Sun, the sail must be tilted at some angle Θ with respect to the Sun-sail line. Since the sail is tilted toward the Sun, the effective collecting area of the prior art solar sail propulsion system is decreased by an amount proportional to $\sin\Theta$.

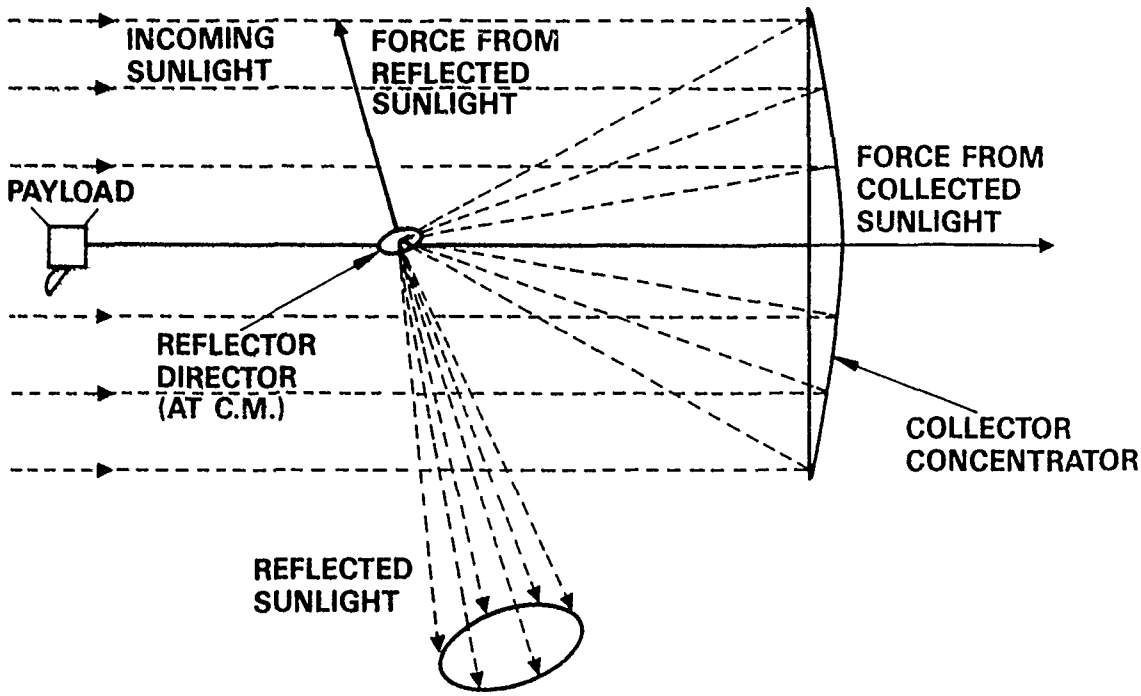

Fig. 1 - The Solar Photon Thruster Concept

This means that the Solar Photon Thruster always collects more solar light power and therefore provides higher total solar photon radiation pressure force for the same area of collector. Since the mass of any optimized light pressure propulsion system is dominated by the mass of the light collecting area, that means that the system of the invention will have better total system performance in terms of maximum payload capability, maximum propulsive thrust, and minimum mission time than prior art solar sail propulsion systems.

Further technical discussion of the Solar Photon Thruster concept can be found in the technical paper accepted for publication in the Journal of Spacecraft and Rockets.[5]

Patent disclosure FUn-88/001 "Solar Photon Thruster", signed 6 May 1988, was subm. cted to the Staff Judge Advocate on 27 May 1988. During a lit(.ature search prior to filing for a U.S. Patent, a drawing of a solar sail structure similar to those in the disclosure was found in a Russian book, which in turn referenced an obscure 1971 Russian publication. This prior art would severely limit the breadth of any claims, so no further action was taken on obtaining a patent.

STATITE: A NON-ORBITING SPACECRAFT

In the statite concept, a space vehicle containing a Earth-services payload (communications, broadcast, weather, navigation, etc.) is attached to a solar light pressure propulsion system to form a space services station. After launch to an altitude where the light pressure propulsion system can function, the light pressure propulsion system is used to place the station at a point above the north or south hemisphere of the Earth where, as is shown in Figure 2, the gravitational pull of the Earth is exactly counterbalanced by the light pressure force from the Sun.

The system of the invention is distinctly different in operation from all other space services concepts, in that the space station supplying the services is not in orbit about the Earth. Unlike all other prior art systems, the system of the invention does not move with respect to the center of the earth and does not use centrifugal force from orbital motion about the Earth to counteract any portion of the Earth's gravitational attraction. Since the spacecraft is not in orbit around the Earth, it is technically not a satellite of Earth.

To distinguish these new types of space vehicles from satellites, the generic scientific term of "statite" has been coined for them, since they are stationary or static with respect to the Earth. Since the major use of the statites will be to service the polar regions, Forward Unlimited has coined the trade name of POLESTAT™ for its versions of the system.

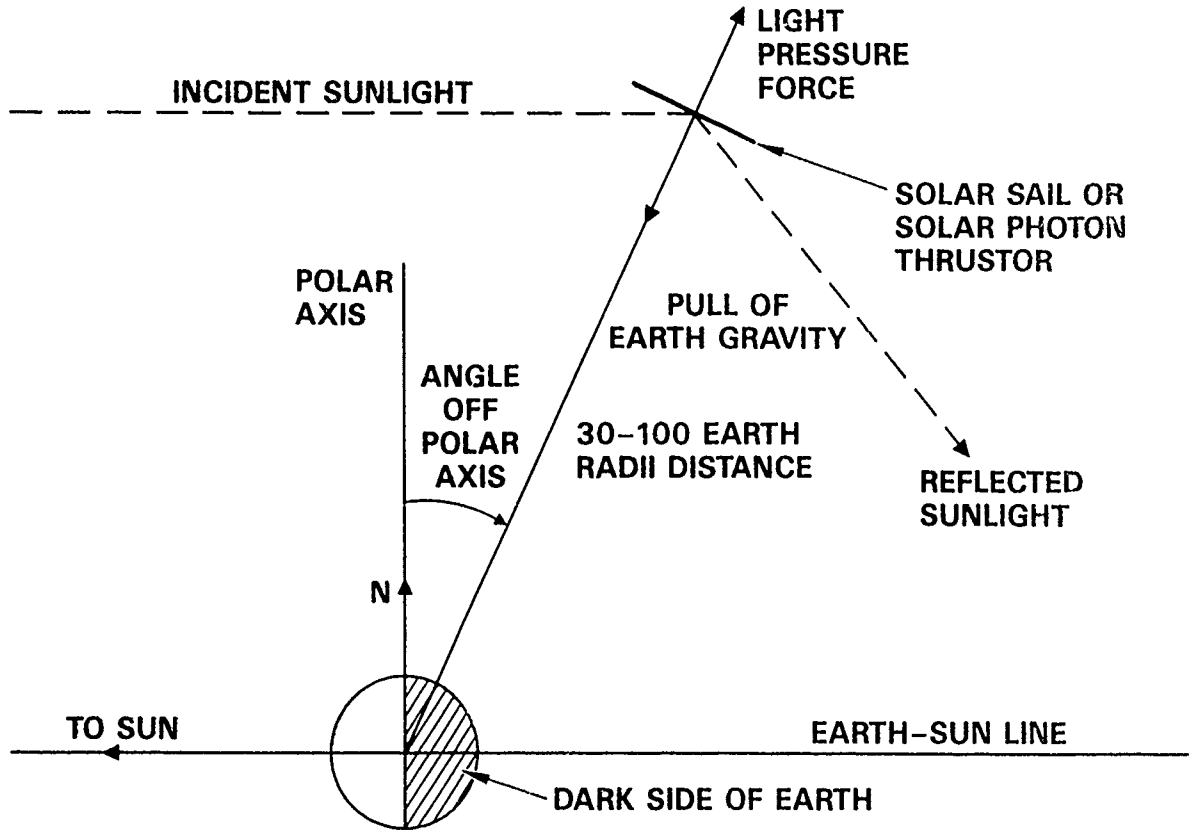

Fig. 2 - The Statite Concept

In some versions of the POLESTAT™ system, the POLESTAT™ is kept directly over the North or South Pole of the spinning Earth. To an observer on the Earth, the POLESTAT™ stays fixed above the pole while the stars rotate around it. The ground stations can used fixed mounted antennas and simple fixed gain, fixed frequency electronics similar to that used for similar services supplied by satellites operating in the equatorial geostationary orbit. In other versions of the system, the POLESTAT™ is offset from the polar axis. It stays fixed at a point above the dark side of the Earth, while the Earth spins beneath it. It should be noted that the statite does not have to be positioned directly opposite from the Sun. The statite can be placed anywhere over a large area on the dark side of the Earth. This is in contrast to the single linear arc of the equatorial geostationary arc.

From the viewpoint of an observer on the rotating Earth, this version of the POLESTAT™ rotates around the pole once every 24 hours (a solar day). Thus, ground stations for communication with these versions of the POLESTAT™ systems must have their antennas on a polar mount with a 24 hour clock drive. Since the distance between the ground station and the statite does not change significantly in magnitude, and the doppler shifts are very low, the electronics needed for these versions of the system of the invention are nearly as simple as those at the fixed position ground stations. A typical distance of a statite from the center of the Earth is 30 to 100 Earth radii. (For reference, geostationary orbit is at 6.6 Earth radii and the Moon is at 63 Earth radii.) Thus, one disadvantage of the system of the invention is that the round-trip delay time is a number of seconds. The basic advantage of the POLESTAT™ system over existing Earth services systems is that the system of the invention can provide continuous service to any region of the Earth, including the polar regions, using only one space vehicle and without requiring a position on the equatorial geostationary arc. Further technical discussion of the statite concept can be found in the technical paper accepted for publication in the Journal of Spacecraft and Rockets.[7]

Patent disclosure FUN-88/002 "POLESTAT™", dated 9 May 1988, was submitted to the Staff Judge Advocate on 27 May 1988. Forward Unlimited filed U.S. Patent Application serial number 07/294,788 "Statite Apparatus and Method of Use" on 9 January 1989. Foreign patents were filed in Japan, Europe, Canada, USSR, and Brazil on 8 January 1990. The U.S. patent application has gone through the first office action and the examiner recognizes the method of the basic concept as being patentable.

CABLE CATAPULT

The Cable Catapult is a proposed new method for high speed interplanetary transport using long space tethers. As is shown in Figure 3, a long tether is pointed in the direction the payload vehicle is supposed to travel. The payload is attached to a linear motor powered by an external electrical source, and the linear motor "climbs" the tether, accelerating the payload up to launch speed. At the launch point, the payload is released to travel on to the destination while the linear motor is decelerated to a halt on a shorter section of cable. When an incoming payload approaches, the linear motor builds up speed, matches with the incoming payload and decelerates the payload to a stop on the longer section.

The major advantage of the Cable Catapult system is that it will allow rapid travel to and from other planetary bodies. Once a complete system is set up, with Cable Catapults at every planet and in the asteroid belt, no energy or propellant will needed to keep the system running provided the incoming mass falling down the Sun's gravity well from the outer solar system exceeds the outgoing mass.

The present method of reaching the planets is to use rocket propulsion. With chemical rockets, the mass ratios are very high, the mission times are years long, and the costs are extremely high. With either nuclear or electric propulsion, the mass ratios are smaller, the costs are slightly less, but the mission times are still many years long. Solar sails have also been considered for interplanetary transport, but the estimated mission times are also many years long.

Existing proposals to use tethers for space propulsion involves rotating a long tether about its center with the payload out at one tip. The maximum launch velocity attainable for practical mass ratios (cable mass over payload mass) is 3 times the characteristic velocity of the cable material or 3 km/s for a 1 km/s cable.

A Cable Catapult using the same amount of cable material could give the payload a launch velocity of 30 times the cable characteristic velocity or 30 km/s. Improved cable materials having higher characteristic velocities will allow interplanetary travel at 30-100 km/s. This could shorten trip times to Mars from years to months or weeks, and open up the whole solar system to rapid, economical transport.

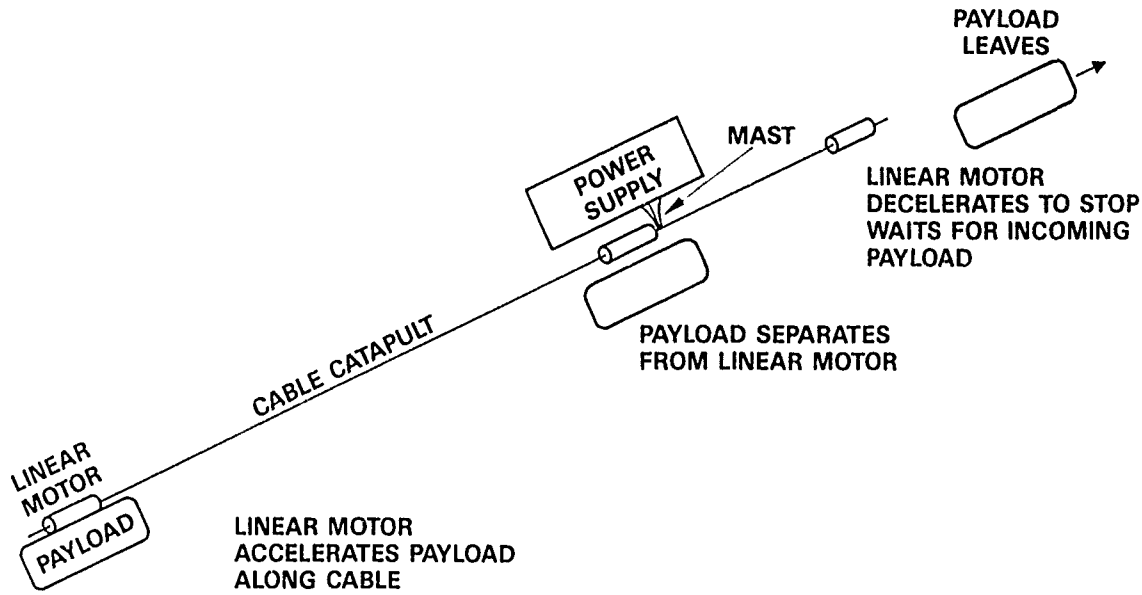

Fig. 3 - The Cable Catapult Concept

The most significant advantage of the Cable Catapult is that the ratio of the cable mass to the payload mass (the effective "mass ratio" of the system) only rises as the square of the final payload velocity divided by the cable characteristic velocity. This is to be compared with a rocket, where the mass ratio rises as the exponential of the final payload velocity divided by the rocket exhaust velocity, or to a rotating tether launcher where the mass ratio rises as the exponential of the square of the final payload velocity divided by the cable characteristic velocity.

The second advantage of the Cable Catapult, is that like the rotating tether, the system can be made conservative, in that incoming payloads will supply most of the energy needed to launch outgoing payloads. Thus, once the system is set up, very little fuel is needed to keep it operating. This is dramatically different from rocket systems, where a mass ratio of rocket fuel is used up for every incoming and outgoing payload.

Further technical discussion of the Cable Catapult concept can be found in the technical paper presented at the AIAA/ASME/SAE/ASEE 26th Joint Propulsion Conference in Orlando, Florida from 16-18 July 1990. The paper has been submitted for publication in the Journal of Spacecraft and Rockets.[9]

Patent disclosure FUN-90/003 "Cable Catapult", dated 5 January 1990, was submitted to the Staff Judge Advocate on 5 January 1990. It was the opinion of the inventor, his company Forward Unlimited, and the patent attorney for Forward Unlimited, that the disclosed invention was patentable. However, Forward Unlimited does not intend to file for a patent, and does not recommend that the U.S. Government file for a patent, since the claims will be quite limited because of the similarity of the disclosed invention to ordinary catapults and railguns, and it is extremely unlikely there will be any commercial application for the concept during the 17 year lifetime of the patent.

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APPENDIX A

TETHER BOOTSTRAP PROPULSION

Dr. Robert L. Forward

7 May 1989

Geoffrey R. Landis of NASA/Lewis Research Center has invented a novel concept for using tethers for propulsion near the Earth.[1] The basic concept is that if two halves of a spacecraft (or a spacecraft and its expended booster) are extended on a long tether (it must be long to be effective), the center-of-mass of the extended system shifts slightly downward from the original center-of-mass and the orbital period decreases. This shift in the center-of-mass occurs because the Earth's gravity force causes an acceleration on the masses that varies as $1/r^2$, while the counteracting centrifugal force due to orbital motion causes an acceleration that varies as r. For very long tethers, the two forces no longer exactly cancel at the two ends and there is a residual, second order, force which must be balanced by a shift in the center of mass. When the tether is pulled in again, the center-of-mass of the combined system raises upward.

By alternately extending and contracting the tether at proper points in the orbit, the tether can be used to "pump" an initially circular orbit into a highly elliptical orbit. Theoretically, if the initial orbit is circular and at an altitude of greater than one earth radii, then the final orbit can be an escape parabola. The angular momentum of the initial and final orbits are the same, so no angular momentum needs to be supplied. The energy of the escape parabola is much greater than the energy of the initial circular orbit, so energy needs to be supplied, either from an onboard power supply or by collecting externally supplied power. The final configuration has the payload, tether, and counterweight flying off away from the Earth at some residual velocity, so it has some linear momentum. To conserve linear momentum, the tether has transferred linear momentum to the Earth by coupling to the gravity tidal fields of the Earth through its extended length.

Although it looks like the system is "pulling itself up by its bootstraps", it is not. In effect, the tether is "climbing" out of the Earth's gravity well by coupling to the non-linearities in the gravitational gradient fields or gravity tides.

Unlike other tether propulsion concepts in the literature, where one mass (the payload) is raised in orbit while another mass (the counterweight) is lowered in orbit, the technique developed by Landis allows the center-of-mass of the entire system to be raised from a low circular orbit into a high elliptical orbit--conceptually into an escape orbit from Earth--without the use of rockets or reaction mass. Energy is required, which can be supplied from an onboard power supply, but no reaction mass is needed, and if the Earth-to-LEO booster is used as a counterweight for the payload mass, the only weight penalty is the mass of the tether (compared with the weight penalty of a LEO-GEO booster rocket).

Further studies have been done by Landis using the simplest pumping scheme, retracting the tether at perigee and extending it at apogee. Since the gravity gradient is stronger at perigee than at apogee, this increases the energy of the orbit. He finds that the technique gets less effective the further the system is away from the Earth, so it would take an arbitrarily long time to actually get all the way to escape.

However, by coupling to the lunar gravitational field on the way out, the system could obviously transfer to a lunar orbit. With the proper choice of a "gravity-whip" trajectory, it could also probably utilize the orbital motion of the Moon reach Earth-Moon escape velocity.

More important from the standpoint of possible Air Force applications of the technique, Landis estimates that it would take only 6.5 days to go from a circular LEO of 0.75 Earth radii (about 5000 km) to a highly elliptical transfer orbit that goes up to GEO. There, a rocket burn could circularize the orbit, or possibly the expended booster (which is also transferred along with the payload) can be tossed away in the right direction to obtain the angular momentum necessary to achieve circular GEO.

Since this new propulsion concept seems to be able to provide useful, reasonably rapid propulsion near the Earth without the use of rockets and only the use of a power supply, which many Air Force payloads have anyway, I recommend that someone in the Advanced Propulsion Branch follow and encourage the work of Landis, and perhaps carry out parallel studies on its feasibility for and applicability to present and future Air Force space missions.

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APPENDIX B

CONTRIBUTION TO MICROSPACECRAFT FOR SPACE SCIENCE WORKSHOP

Dr. Robert L. Forward

9 July 1990

INTRODUCTION

The material in this technical report is designed to be used as input draft material for potential inclusion in the Summary Report of the Microspacecraft for Space Science Workshop held at the Jet Propulsion Laboratory on 6-7 July 1988. The Summary Report will be compiled by Ross M. Jones and James D. Burke of JPL. The report will contain presentations given to a panel of invited science and technology experts, and a report by the panel summarizing their findings as to the science value and the technological feasibility of the concept of using microspacecraft for space science, and the directions for future development of the concept.

Because this report is merely input material to a larger report, it is broken into short, self-contained sections to make the jobs of the Summary Report editors easier. The casual reader will find this report disjointed and incomplete, since it is only part of a whole. It is recommended that the interested reader obtain the full Summary Report from Ross M. Jones, Mail Stop 233-309, Jet Propulsion Lab, 4800 Oak Grove Drive, Pasadena, CA 91109 USA, telephone (818)354-7769.

This research was supported in part by the Air Force Astronautics Laboratory through contract F04611-87-C-0029 with Forward Unlimited, and in part by the NASA Office of Aeronautics and Space Technology and the SDIO Innovative Science and Technology Office through their financial support of the Microspacecraft for Space Science Workshop at JPL.

SUMMARY

As a member of the panel of invited science and technology experts (with a foot in both camps), I would summarize the presentations and discussions as follows:

Spacecraft

The present and future development of hit-to-kill projectiles by the Space Defense Initiative Organization gives strong confidence that the technologies necessary for the development of spacecraft buses suitable for microspacecraft will be available when they are needed. The vehicles can be made with a mass less than 5 kg, provide both inertial and imaging guidance, a reasonable divert Δv of 1-2 km/s, telemetry over 1000s of kilometers, large amounts of computing power, and still have a significant mass fraction available for science payloads.

Because these buses were designed for a different mission than interplanetary space science, there are some major areas that need further careful examination to make sure that some "show stopper" does not lurk somewhere. Some examples that come immediately to mind are:

- The design lifetime for the SDI mission is in minutes, while interplanetary missions take years. Is the design mean-time-to-failure of inertial reference unit, propulsion system, electronics, etc. compatible?
- The design ranges for the SDI mission are in 1000s of kilometers, not A.U. Can reasonable extrapolations of the onboard power, telemetry, transmitting and receiving apertures, optical focal lengths, etc. be made to allow the weapon turned science spacecraft to perform its new mission?
- The design accelerations are 100s to millions of gees. Are there any science instruments that cannot be redesigned to take these accelerations?

The presentations at the workshop on spacecraft concepts were largely limited to spacecraft buses that were compact versions of present spacecraft, in that they use onboard propulsion and the scientific payloads are not integral parts of the structure. This was proper, since such spacecraft seem feasible in near term, are very flexible in the type of payloads they can carry, and seem adequate to carry out the desired scientific missions. There do exist other concepts for spacecraft structures, however, some specific examples being atmospheric and ground penetrators, sails, and tethered structures (no doubt there are others that would be uncovered by a more thorough search), that were not discussed in any detail. Some of these may be more suitable, or even enabling, for some types of missions.

An example of the penetrator type is the atmospheric penetrator "Maple Seed" concept briefly flashed up by James Burke.[1] There is no onboard propulsion for rendezvous with the planet, with the "wing" serving as a tail during reentry, an autogyro for soft landing, and an antenna during data return.

An example of the sail type is the wire mesh spacecraft concept conceived by Freeman Dyson and Robert L. Forward, and described in a paper by Forward.[2] The spacecraft structure, propulsion system, power supply, electronics package, navigation system, imaging system, and transponder/data return system are all integrated into a single structure, a hexagonal wire mesh with integrated electronic circuits at the intersections of the wires. Beamed microwave power striking the wire mesh provides propulsion, electric power to run the circuits, and an electronic phase reference to the transponder giving the direction back to Earth.

An example of the tethered structures would be a large VLF radio array consisting of radio receivers held in a square array by tethers such as that discussed in the presentation by Tom Kuiper.[3] For the VLF array, the tethers would serve both as antennas and structure.

Propulsion

The propulsion concepts discussed at the workshop were primarily limited to electromagnetic guns (more specifically railguns), and chemical propulsion (both for launch and divert Δv). The one paper on laser propulsion by Tom Meyer[4] on the second day, was on a next generation laser photon pressure propulsion concept. A better picture of the status of laser propulsion can be found in the Proceedings of the SDIO/DARPA Workshop on Laser Propulsion held in July 1986 at Lawrence Livermore National Laboratory.[5]

The presentations on propulsion showed that existing chemical rocket technology could serve to send clusters of microspacecraft on their way, and that if electromagnetic guns existed in space, they also would do for firing compact macro projectiles (microspacecraft) to the planets. There was a general feeling, however, that straightforward extrapolations of chemical propulsion ideas would not produce the breakthrough in cost reduction and frequency of launch that would truly make microspacecraft a reality. Innovative launch, midcourse, and terminal propulsion ideas are needed and the recommended survey study should search diligently for them. If they are not found, and SDIO does not develop them for its purposes, then the microspacecraft concept will literally "not get off the ground".

Communications

It is amazing how far one can talk on one watt. The presentations on telecommunication and power subsystems by Dick Turner,[6] indicate that reasonable data rates can be expected back from microspacecraft, especially if the carrier frequency is shifted into the optical region. There was a general feeling, however, that the telecommunications bit rates that looked reasonable to the communication technologists were not much greater than the maximum data bit rates desired by the scientists (especially for flyby imaging missions). This could be a potential problem area. The problems of the deterioration and overloading of the Deep Space Network, the desire of investigators to collect data full time, directly at their own site, means that innovative thinking is needed, and the recommended survey study should look carefully for "show stoppers" in this area.

Science Sensors

Another area that was only briefly scanned over in the presentations at the workshop were the compatibility of typical science sensors with microspacecraft and missions enabled by them. Practically all the present space qualified science sensors are too heavy for microspacecraft. Some science sensors, such as gamma ray detectors and gravity gradiometers, lose sensitivity with reduced mass. Some science sensors, such as long focal length telescopes, VLF antennas, high resolution imaging systems, and magnetic gradiometers, need long lengths or large areas. Although these can be supplied by light-weight construction, the resultant rigidity may not be enough for proper sensor performance. Some science sensors, such as magnetometers and gamma ray detectors, require low background levels, and may not be compatible with certain types of microspacecraft. Again, this is an area that needs further study in any survey.

Science Missions

One obvious conclusion of the workshop is that microspacecraft will not replace macrospacecraft. As Freeman Dyson eloquently expressed it during the summary session, "Don't confuse science with exploration." Microspacecraft are clearly appropriate for exploration, and there are some specific science missions that are enabled by the microspacecraft concept. As an example of using many microspacecraft for exploration, the asteroid belt can be sampled in a statistically significant manner by 100s to 1000s of simple penetrators that take one or two photos on the way in, sample a few distinguishing properties a meter or so under the surface, and telemeter the data back to Earth at leisure. A distant moon or planet can be explored globally by dropping a swarm of a few dozen "maple leafs" or penetrators from all angles.

As an example of microspacecraft being an enabling technology for a science mission, a comprehensive study to determine both the spatial and temporal structure of the magnetosphere around the Earth, Sun, or other body cannot be done with one or two large spacecraft. It can be done, and done well, with a single launch that places a few dozen microspacecraft into appropriately displaced orbits.

There are no doubt other science missions that can be aided or enabled by the availability of microspacecraft. Some of these concepts will be new ones that will be conceived by the scientists in those fields only when they realize that microspacecraft are possible. The proposed study should include a survey of space scientists that essentially asks: "Suppose you could place 100s of spacecraft or landers anywhere you wanted to. What could you do with them? What capabilities should they have?"

RECOMMENDATIONS

It is recommended that further work on microspacecraft for space science proceed. The concepts for the spacecraft technology look reasonable and there are definite science missions that cannot be done using present space exploration concepts.

It is recommended that a full-time person or a small group of persons conduct a broad survey of the field and prepare a report summarizing the present and future state of the technology of microspacecraft and the space science uses of that technology. The various concepts that were noted, but not covered, in the workshop should be investigated in detail. Special effort should be made to find new spacecraft concepts, new propulsion concepts, new instrument concepts, and new applications of microspacecraft that were not brought out at the Workshop. For example, potential science users should be surveyed to uncover new science missions.

Because the concept covers so many fields, the study should allow sufficient real time (12 months), in addition to sufficient man-power (1.5 my for one person plus literature search help, 5 my for a team) to allow for follow-up of new concepts that are discovered in the first phases.

It is recommended that a review article on microspacecraft be submitted to Aerospace America. Other popular articles also need to be written and color art prepared to make the engineering and scientific community aware of the concept.

It is recommended that as the survey report nears completion (about 18 months from now), a second workshop be convened. This should have sufficient funding so that review papers by well-known scientists and technologists can be commissioned ($2000-$5000

each) beforehand, on specific critical topics uncovered by the survey study. The proceedings of this workshop should be published as a book (World Scientific Publishing, Singapore is fast), to get archival abstract and library attention. (Bruno Augenstein of RAND Corporation just produced such a proceedings of commissioned papers for the Antiproton Science & Technology Workshop.)

References

[1] James Burke, "Mars Maple Seed" (see contribution).

[2] Robert L. Forward, "Starwisp: An Ultra-Light Interstellar Probe", J. Spacecraft, Vol. 22, No. 3, pp. 345-30 (May-June 1985).

[3] Tom Kuiper, "Sub-millimeter Waves" (see contribution).

[4] Tom Meyer, "Laser Levitated Microspacecraft" (see contribution).

[5] J.T. Kare, Technical Editor, Proceedings SDIO/DARPA Workshop on Laser Propulsion, LLNL, Livermore, CA, 7-18 July 1986. Vol. 1 - Executive Summary (Nov 1986); Vol. 2 - Contributed Papers (April 1987). LLNL Report CONF-860778, Technical Information Dept, Lawrence Livermore National Laboratory, Livermore, California 94550.

[6] Dick Turner "Telecommunication and Power Subsystems" (see contribution).

GOSSAMER SPACECRAFT

The presentations at the workshop on spacecraft concepts were largely limited to spacecraft buses that were compact versions of present spacecraft, in that they used onboard propulsion and the scientific payloads were not integral parts of the structure. This was proper, since such spacecraft seem feasible in near term, are very flexible in the type of payloads they can carry, and seem adequate to carry out the desired scientific missions. There do exist other concepts for spacecraft structures, generically referred to as "Gossamer Spacecraft" by Bruce Murray.[G1] Some specific examples are strings, tethers, sails, nets, and balloons (no doubt there are others that would be uncovered by a more thorough search), that were not discussed in any detail. Some of these may be more suitable, or even enabling, for some types of missions.

An example of a string spacecraft would be one consisting of a small, thin conducting fiber with a central payload consisting of a semiconductor diode microwave generator, a field emitting needle, and a few micrograms of radioisotopes that can emit high energy beta particles that would charge up the whole spacecraft to the voltage of the emitted particle (many megavolts). The rapidly moving charged spacecraft would experience Lorentz forces proportional to the interplanetary magnetic field. By properly designing the position of the charging radioisotopes and the discharging field emission points, currents can be made to flow in the metal coated portions of the fiber and used to power microwave diodes, making them oscillate. The rf energy can be radiated into space by the fiber acting as a multielement array of electromagnetic dipoles with a very large effective area. By tracking these charged wires as they move through space, the strength and direction of the magnetic field, and possibly even the ion density, can be calculated.[G2]

An example of the tethered structures would be a large VLF radio array consisting of radio receivers held in a square array by tethers such as that discussed in the presentation by Tom Kuiper.[G3] For the VLF array, the tethers would serve both as antennas and structure.

Tethers can also be used for propulsion. A rotating cable around the earth can pick up payloads at the peak of a ballistic trajectory launch and whirl them around to escape velocity. The minimum rotating tether mass was found to be 75 times the payload mass.[G4] If this scaling law holds for microspacecraft, a half-ton rotating tether can easily throw one 5 kg microspacecraft after another anywhere in the solar system.

Alternatively, a chemically launched microspacecraft approaching a planet can use its expended boost stage as a counter-weight on the end of a tether. By proper phasing of the rotation of the pair with respect to the approach trajectory, and a timely cutting of the tether, the counter-weight goes flying off into d the payload goes into a capture orbit around the planet w. expenditure of propellant.

An example of the sail type is the well-known JPL study for the design of a solar sail capable of rendezvousing with Halley's Comet.[G5] JPL has known this technology would work for over a decade, and I was surprised that someone did not take a quick look at microsails for the workshop. This should be done in the recommended study.

An example of the net type is the wire mesh spacecraft concept conceived by Freeman Dyson and Robert L. Forward and described in a paper by Forward.[G6] The spacecraft structure, propulsion system, power supply, electronics package, navigation system, imaging system, and transponder/data return system are all integrated into a single structure, a hexagonal wire mesh with integrated electronic circuits at the intersections of the wires. Beamed microwave power striking the wire mesh provides propulsion, electric power to run the circuits, and an electronic phase reference to the transponder system giving the direction back to Earth.

The array of integrated circuits, each with a photodiode and interconnected through the wires, can use the large effective aperture to collect photons at different frequencies from different directions, transform the information into a high resolution multi-color image, and transpond the image back. The original paper showed how 16 grams of wire mesh and 4 grams of electronic microcircuits could return real-time color television pictures over interstellar distances. The size of the transmitting microwave aperture in the paper was extreme because of the high terminal velocity required to conduct interstellar travel.

This concept should be reevaluated for its suitability for imaging science of the distant planets. If such large area-to-mass ratio mesh structures could be shown to survive reentry into planetary atmospheres, then the microcircuits payload could include electromechanical mechanisms,[G7] chemical sensors, and other sensors for surface and atmospheric sampling.

References

[G1] Bruce Murray, "Gossamer Spacecraft Workshop", JPL, 1980.

[G2] Robert L. Forward, "Zero Thrust Velocity Vector Control for Interstellar Probes: Lorentz Force Navigation and Circling", AIAA Journal, Vol. 2, No. 5, pp. 885-889 (May 1964).

[G3] Tom Kuiper, "Sub-millimeter Waves" (see contribution).

[G4] Hans Moravec, "A Non-Synchronous Orbital Skyhook", J. Astronautical Sciences 25, 307-322 (October-December 1977).

[G5] L. Friedman, et al., "Solar Sailing--The Concept Made Realistic", AIAA Paper 78-82, AIAA 16th Aerospace Sciences Meeting, Huntsville, AL (January 1978).

[G6] Robert L. Forward, "Starwisp: An Ultra-Light Interstellar Probe", J. Spacecraft, Vol. 22, No. 3, pp. 345-30 (May-June 1985).

[G7] Bill Trimmer, "Micromechanical Systems" (see contribution).

LASER PROPULSION OF MICROSPACECRAFT

There are two forms of laser propulsion--laser photon pressure propulsion and laser thermal propulsion. In laser photon pressure propulsion, the microspacecraft is made highly reflecting at the laser operating frequency (usually by extending a reflective sail) and bouncing the laser light off the spacecraft. The laser photons have momentum, and the change in the direction of the momentum vector during the reflection process produces an impulsive force on the spacecraft given by:

$$F = 2P/c$$

where P is the laser power and c=300 Mm/s is the speed of light.

The concept of laser lightsail propulsion was conceived in 1961 within months after the invention of the laser.[L1] A paper reviewing the field and discussing the application of laser-pushed lightsails for round-trip interstellar travel was published in 1984.[L2] The concept is not limited to laser light bouncing off mirrors. For example there is one design that uses beamed microwave power to push a reflective wire mesh structure.[L3]

This form of laser propulsion has the advantage that the laser supplies both the energy and the reaction mass for the propulsion system. Since the reflected laser light still has most of the power in it, however, this method of laser propulsion is extremely inefficient in coupling the laser power into the vehicle to produce kinetic energy in the vehicle. In the parlance of the propulsion engineer, the "specific impulse" is too high for the mission. A better method of using laser power for solar system exploration is laser thermal propulsion.

Laser thermal propulsion was first proposed by Kantrowitz[L4] in 1972, shortly after the advent of high power CO_2 lasers. Until recently, however, there did not appear to be much prospect of obtaining large enough lasers to launch useful payloads from the ground. The characteristic laser power required has typically been taken to be 1 GW or larger. Laser propulsion studies supported by NASA, DARPA, and the Air Force have concentrated on orbital maneuvering missions requiring high Δv, but modest thrust levels corresponding to laser powers around 10 MW.

Recently, much progress has been made in the development of high power lasers, especially free electron lasers (FELs), and in related technologies such as adaptive optics. This work, supported by the defense community and particularly by SDIO and DARPA, has led to the expectation that lasers (and optics) capable of launching significant payloads to orbit will be demonstrated by the early 1990s. Because of this expectation, the SDIO and DARPA sponsored a Workshop on Laser Propulsion at the Lawrence Livermore

National Laboratory from 7-18 July 1986.[L5] The meeting was held at LLNL since they are in the process of constructing a free electron laser with peak and average power levels that are classified, but clearly within the range of suitability for consideration as a laser source for testing vehicles with laser thermal propulsion systems.

A summary of the workshop results are:

CW laser thermal propulsion is a significant new form of advanced rocket propulsion that can be used for both earth-launch and orbit-raising missions.

- Engine efficiencies as high as 90 to 100% can be achieved by regenerative cooling of the absorption chamber and by operating at optimum flow rates, pressures, and optical geometries.

- Specific impulses of 2000 s (exhaust velocities of 20 km/s) can be achieved and can be varied for optimum propulsion throughout a mission.

- The physics of the CW laser thermal propulsion process are well understood, and scaling studies can now be undertaken.

- Because the physics are understood and no serious problems have been identified, working prototype CW thrustors should be available by the early 1990s.

CW laser thermal propulsion is best suited for high-energy missions requiring very high specific impulses. Some examples are:

- Orbital maneuvering in low earth orbit or to geostationary orbit. The laser power required is 10 to 100 MW.

- Inexpensive launch of 1000 kg payloads into low earth orbit. The laser power required is 1 to 2 GW.

References

[L1] Robert L. Forward, "Pluto-The Gateway to the Stars", Missiles and Rockets, Vol. 10, pp. 26-28 (April 1962).

[L2] Robert L. Forward, "Roundtrip Interstellar Travel Using Laser-Pushed Lightsails", J. Spacecraft, Vol. 21, pp. 187-195 (March-April 1984).

[L3] Robert L. Forward, "Starwisp: An Ultra-Light Interstellar Probe", J. Spacecraft, Vol. 22, pp. 345-350 (May-June 1985).

[4] Arthur Kantrowitz, "Propulsion to Orbit by Ground-Based Lasers", Astronautics and Aeronautics, Vol. 10, pp 74 ff (1972).

[5] J.T. Kare, Technical Editor, Proceedings SDIO/DARPA Workshop on Laser Propulsion, LLNL, Livermore, CA, 7-18 July 1986. Vol. 1 - Executive Summary (Nov 1986); Vol. 2 - Contributed Papers (April 1987). LLNL Report CONF-860778, Technical Information Dept, LLNL, Livermore, California 94550.

APPENDIX C

THE WEBER EFFECT

Dr. Robert L. Forward

4 May 1989

Background

Professor Joseph Weber of the University of Maryland and University of California at Irvine has carried out a series of experiments in which he reports that he has observed anomalously high scattering of neutrinos from nearly perfect crystals with high Debye temperatures. I will call the experimentally observed enhanced neutrino scattering, "The Weber Effect", since it is an observed experimental effect that exists independent of theories. Weber has also developed a theory to explain his experimental results. I will call his theory "The Weber Scattering Center Coherence Theory". It is important to recognize that "The Weber Effect" is separate from "The Weber Scattering Center Coherence Theory". The Weber theory could be wrong, while the Weber Effect could still exist.

Most of the physics community do not believe either in the Weber Scattering Center Coherence Theory or the Weber Effect. A number of papers have been written criticizing his theoretical analysis. Because they don't believe his theory, most physicists dismiss all of his work out of hand and have not attempted to verify his experimental results. To me, the experimental results, because of their large number and great variety in terms of different particles, different sources, different detectors, and different setups, have a validity that is independent of theory. The experiments deserve attention, and they have not gotten it.

It would be different if the Weber Effect were some trivial phenomenon of interest to only a small group of specialists. But if the Weber Effect is real, there could be major military and geopolitical implications. A sensitive directional detector of neutrinos would make the seas transparent as far as nuclear powered submarines are concerned. Nuclear reactors and most nuclear weapons could not be hidden unless the same concept were used to develop neutrino shields.

If the Weber Scattering Center Coherence Theory is found to be correct, and applies to other particles than neutrinos, then improved detectors for many other particles (infrared light, gravitons, axions, cosmic rays) might become available, producing major technological advances in sensors and communication.

In this report I will outline and discuss the experiments demonstrating the Weber Effect, briefly cover the Weber Scattering Center Coherence Theory, and recommend some experiments that could be carried out by the Astronautics Laboratory that would augment experiments being conducted or planned elsewhere.

Experiments

Most of the experiments demonstrating the Weber Effect have been carried out over the past eight years by Professor Weber himself. Recently, experiments have been done by others in cooperation with Weber. One early experiment[1,2] by Weber used the antineutrinos from a 600 Ci (curie) tritium source to create a repulsive force of 4×10^{-7} dynes on a 12.7 g crystal of sapphire (aluminum oxide) 2.54 cm in diameter (5.1 cm^2 area) and 0.38 cm thick with approximately 1000 dislocations per square centimeter[3], and a Debye temperature of 1000 K. A 600 Ci source produces 2×10^{13} antineutrinos per second. Weber estimates that the antineutrinos have an average energy of about 12 keV. I would estimate the neutrino energy would be half the tritium decay energy of 18.6 keV, since the neutrino shares the energy with a beta particle. The repulsive force was measured using a sensitive torsion balance made of a tungsten fiber supporting an aluminum disc with the sapphire crystal on one side and a dummy weight of lead on the other. The measured force of 4×10^{-7} dynes corresponds to a total cross section of approximately 1.5 cm^2, which is almost the physical cross section of the crystal.

The experiment was repeated[2-4] with a 3000 Ci source, a sapphire crystal with diameter of 2.54 cm (area 5.1 cm^2) and a thickness of 0.6 cm, with essentially the same results. The calculated experimental neutrino scattering cross-section was 2.05 ± 0.23 cm^2, or again almost the physical size of the crystal. The 3000 Ci source generates about 0.1 W as the result of the beta decay electrons being stopped in the container. Possible thermally induced effects due to this heating were reduced by using a resistive heated dummy capsule with the same size, mass, and heat output as the tritium source.

Another experiment[1,4] employed antineutrinos from a nuclear test reactor at the National Bureau of Standards in Gaithersburg, Maryland. The average energy of the reactor neutrinos was estimated by Weber to be 1.6 MeV. A standard torsion-balance arrangement was used, with a 100 g sapphire crystal on one side and a 100 g lead mass on the other. A 5 kg "shield" crystal was used to "block" the antineutrinos coming from the reactor. The apparatus was located about 15 m from the 20 MW nuclear reactor. Repulsive force changes of $3.9 \pm 0.4 \times 10^{-5}$ dynes, were observed as the shielding crystal was placed between the reactor and the target crystal. The calculated cross section was approximately 2 cm^2 for a 100 g crystal.

A third experiment[4] involved solar neutrinos. The torsion balance had a 26 g single crystal of sapphire on one side and a lead mass on the other. The solar neutrino flux is expected to be $6x10^{10}$ neutrinos/s•cm^2 ($6x10^{14}$ neutrinos/s•m^2), with an energy range from 0 to 430 keV. A diurnally varying force of about $4.6x10^{-6}$ dynes was observed.

There are also two experiments that do not involve neutrinos scattering off stiff crystals. Unfortunately, the experimental details are very sketchy, since these experiments show that a large "Weber Effect" exists in experimental setups that do not involve crystals and neutrinos. One experiment[1] involved the heating of a nuclear spin system in a magnetized target crystal, associated with inelastic coherent scattering of the antineutrinos from the reactor. No mention is made of scattering cross-section measurements.

The other experiment is described in a brief contract progress report[5] which describes the anomalously high absorption of photons by nuclear spins in a cryogenically cooled crystal. Again the effect is purported to be due to coherent action by the scattering centers. These results have yet to be reported in the scientific literature. If they are true, they indicate that the anomalously high cross sections are not due to some peculiarity of neutrinos, but can be repeated using easily generated and detected laser photons.

There have been two recent experiments to verify the Weber Effect that involve other people besides Weber and his students and employees. The first is an experiment carried out by Mario D. Grossi, of Smithsonian Astrophysical Laboratory (SAO) and Raytheon Submarine Signal Division. Dr. Grossi had been under contract to NASA[6] and then DARPA[7] for research on a mechanical method for detecting neutrinos by modifying a cryogenic gravity gradiometer structure to be a neutrino detector. The theory his neutrino detector was based on was not the Weber Theory, but a neutrino refraction theory[8] developed by Robert R. Lewis of the University of Michigan-Ann Arbor. The Lewis theory predicts a very much smaller effect than the Weber theory.

Dr. Grossi was directed by his DARPA contract monitor, Lt. Col. Lasche, to redirect his experimental effort into a test of the Weber Effect using a torsion balance detector supplied by Prof. Weber, a tritium source of neutrinos supplied by Los Alamos National Lab (LANL), and a rotating table to rotate the source past the torsion balance. The work was carried out from August 1988 to January 1989 and is described in a two volume contract report[7] dated 31 January 1989.

The torsion balance was mounted at a fixed location, close to the edge of the 1 RPM rotating table. On the edge of the table was placed either a 100 kilocurie tritium filled container (the

neutrino source) or a deuterium filled container (providing an equivalent gravity force source for reference). As the table rotated, the sources were moved by the torsion balance, which responded to the combination of gravity and neutrino forces from the sources.

The experiment consisted of a comparison between the output of the torsion balance, integrated each time for 168 hours (10,080 rotations of the 1 RPM table), first using the deuterium filled sphere and then using the tritium filled sphere. There was a difference between the integrated outputs. This difference would be consistent with a repulsive force which is present when the tritium is used. The intensity of this repulsive force was approximately 10^{-11} N (1 microdyne). This repulsive force is an order of magnitude smaller than the attractive gravity force from the 2.6 kg spherical containers, and compatible to the observations that Prof. Weber had seen at the University of Maryland in 1986 with his 3000 Ci source.

The experiment was repeated with a 1/4 inch lead shield wrapped around the 8 inch diameter cylinder that houses the torsion balance. This time, there was no difference greater than random noise between the two sets of data (one for the tritium source and one for the deuterium source). This set of experiments would seem to indicate that the Weber Effect is real, but is caused by something that can be shielded by a quarter-inch of lead. However, Dr. Grossi considers this only a preliminary result, and he emphasizes that no conclusions, either positive or negative, should be drawn from these two preliminary sets of data. First, the integrated signals are just barely above the remaining noise (see Figs. 2.3-1, p. 72 and 2.3-3, p. 76 in the contract report[7]) and the runs need to be repeated to be believed. Second, during the second set of runs with the lead shield, the temperature changed in the laboratory, and the period of oscillation of the torsion balance changed significantly between the run with the deuterium sphere and the tritium sphere (see Fig 2.3-2, p. 75 in contract report[7]). The data had to be "stretched" in time in order to compare the curves, raising many questions about the validity of the result.

There were no additional experiments done, not even a repeat of the first two experiments. This was primarily because funding had run out, but in addition, a number of things needed to be fixed before additional experiments could be attempted. First, the torsion balance had a very small damping factor (about 6%) and a period of 14 s, so it would still be swinging from the previous impulse when the 1 RPM table brought the source around again one minute later. It would be desirable to have the balance critically damped. Second, the period of oscillation of the torsion balance changed by 5% when going from summer time (1988) to winter time (1988/89) at LANL, so thermal insulation or thermal control would be desired for the torsion balance. This would also

improve the drift, which was significant over the course of the 168 hour experiments. Third, with the gravity signal being much larger than the neutrino signal, the neutrino signal was difficult to extract. By adding 25 identical deuterium-filled spheres to the table, the impulse caused by the gravitational attraction of the tritium source sphere would be smoothed out into a constant force, allowing the neutrino repulsive force to become 50 times larger than the residual 1 RPM gravity force component rather than 10 times smaller.

There was one last experiment done, which has not yet been written up. The following information is condensed from lengthy conversations I had with both Prof. Weber and Lt. Col. George Lasche. Since it is a recollection, there may be some errors.

Prof. Weber has invented a new type of detector system. The apparatus consists of two components, a chopper wheel to modulate the flux of neutrinos and a resonant tuning fork detector tuned to the neutrino modulation frequency. The chopper wheel consists of a metal wheel with six sapphire crystals mounted in holes near the circumference. The crystals are 1.5 in. (3.8 cm) in diameter and 2 in. (5 cm) long. The crystals are supposed to temporarily block the neutrino flux, producing a modulated beam. The wheel is rotated at 500 RPM, and with six crystals on the wheel, the resulting modulation frequency is 50 Hz. The detector proper is a tuning fork with a sapphire crystal 1 in. (2.5 cm) in diameter and 2 in. (5 cm) long on one arm and an aluminum matching weight and a piezoelectric crystal on the other. The resonant frequency of the loaded tuning fork is 50 Hz. It has a Q of 2000 (1/e ringdown time of 13 s).

The modulated neutrino beam from the chopper would exert 50 Hz forces on the sapphire crystal due to the Weber Effect, and the resonant tuning fork would respond by vibrating. The piezoelectric crystal converts the tuning fork vibrations into electrical signals at 50 Hz, and these electrical signals are amplified and detected by a phase sensitive synchronous detector. This detection method is similar to that used in gravitational radiation antennas[2] and resonant gravity gradiometers[9]. It is relatively easy to achieve thermal noise limited detection sensitivity in such room temperature resonant mechanical systems.

In November 1988, Prof. Weber took the chopper wheel and the tuning fork detector apparatus to the 10-20 MW nuclear reactor at the National Bureau of Standards at Gaithersburg, Maryland. With him, observing and collecting data, was his DARPA Contract Monitor, Lt. Col. George Lasche. When the chopper wheel was operating properly and the phase on the single-channel lock-in amplifier was properly adjusted, a very strong ("booming") signal was observed from the resonant tuning fork detector.

When a blocking crystal of sapphire was interposed between the chopper and the detector the signal dropped. When a new crystal of different material than sapphire was interposed, the signal dropped even more. When the blocking crystals were placed in front of the chopper, further from the tuning fork detector, the signal was smaller, but still significant. When a block of lead or polyboron (to absorb any neutrons) was imposed, there was no decrease in the signal level.

Twenty-seven sets of data (14 pairs, blocked and unblocked, each ten minutes long) were taken. They were analyzed blind by Lt. Col. Lasche using a Student's T test. A definite signal was found, with a probability of error less than 1% when sapphire was used as the blocking crystal, and with negligible probability of error with the much larger signal obtained when the new crystal was used to block the neutrinos. These experiments showed that the Weber Effect is real and easy to see using a chopping wheel and a resonant detector. The experiments using the lead and polyboron showed it is probably not due to X-rays or neutrons. The nature of the new crystal with better scattering properties than sapphire is proprietary to Professor Weber.

The present plans for experimental work in the near future involve two efforts, both funded by DARPA. The first one, to start in May or June 1989, will involve an effort by Prof. Weber to construct an improved version of the chopper wheel and detector using the new crystals. The improved equipment will be tested on the neutrinos from the reactor at NBS, Gaithersburg.

The second effort, to start in June, July, or August 1989 (depending upon how fast the contract mill grinds) will be a continuation of the effort by Mario Grossi of SAO and others to measure, at LANL, the effect of the neutrinos from a 100 kilocurie tritium source on the Weber torsion balance apparatus. Professor Weber has improved the damping in the torsion balance so that it is nearly critically damped. The table will have 26 replicas of the tritium source so that the Newtonian gravitational field attraction contribution of the tritium source will be smoothed out, allowing the repulsive neutrino force to stand out. Various shields, plus X-ray and neutron detectors, will be used to determine if any observed repulsive force is due to some other effect than scattering of neutrinos.

The Weber Scattering Center Coherence Theory

Weber has published[1-4] a theoretical explanation of the high scattering cross section for neutrinos. The theory attributes the high value to a coherent interaction of the scattering centers (which are the nuclei of the atoms in the crystal), which causes the cross section to increase by the square of the number of scattering centers. The Weber coherence is due to interactions of

the nuclei with each other through the elastic fields in the crystal and has nothing to do with the "wavelength" of the neutrino. It is essentially the same type of "coherence" between nuclei in a crystal that is used to explain the Mössbauer effect, but in reverse. For a small crystal, the number of scattering nuclei is of the order of 10^{22}, so the coherence effect increases the scattering cross section by a factor of 10^{44}. When this enhancement factor is multiplied by the typical neutrino scattering cross section for a single nucleus of 10^{-44} cm^2, the scattering cross section for the whole crystal is near the physical cross section for the crystal.

Many papers have been written[10-18] proving that Weber's theory is wrong. Weber, of course, does not agree with them. Arguments have been made that similar anomalously high scattering cross sections should have been observed in X-ray or neutron scattering from crystals. The interactions of these other particles through electromagnetic forces and strong nuclear forces may be different than the interaction of neutrinos through the weak nuclear force. Also, an essential condition for the coherence mechanism is that the crystal be nearly perfect, with an extremely low dislocation density. If the scattering centers are not all strongly coupled together by the crystal fields, then the coherence effect does not take place. A crystal with many dislocations could be considered as 10 separate crystals, and since the coherence effect goes as the square of the number of scattering centers in each crystal, the total cross section of 10 crystals is 1/10 the total cross section of one crystal of the same mass. Weber uses semiconductor-grade sapphire crystals with very low dislocation densities. The new crystals he has discovered have near zero dislocations. It is very doubtful that the crystals used in past X-ray and neutron scattering experiments were of this quality.

The Scattering Process

The scattering process that occurs in the Weber Theory of Scattering Center Coherence is difficult to visualize. It is not like the reflection of light by a mirror, it is not like the refraction of light by a dielectric, it is not like the absorption of light by a black surface, and it is not like the scattering of X-rays by a crystal. It is a volumetric scattering of high efficiency, low angle, and minimal absorption, somewhat like the scattering of neutrons by a moderator, except that in the process of the scattering of a neutron off the moderator atoms, the neutron energy is changed.

According to Weber, because the calculated cross sections given by the theory exceed the physical size of the crystal area, the probability of scattering is so high that all the neutrinos have scattered at least once by the time they have passed through a thin surface layer of the crystal. Yet, according to another

statement by Weber[4], "the exponential factor [in the theoretical equation] implies that the scattering is in a narrow cone in the forward direction. Thus the MeV antineutrinos [from the nuclear reactor], while multiply scattered, continue to move mainly in the forward direction."

I have found the following visualization of the scattering process helpful. Imagine a person trying to build an instrument to detect the light pressure of the photons coming from the sun using only transparent dielectrics. He has no conducting materials to make mirrors or absorbers. He needs something to convert the light photons into mechanical motion. Unfortunately, the light photons pass right through the transparent materials in his instrument without producing any net light pressure. If, however, he makes a disc of transparent material with lots of tiny transparent bubbles in it, it will become translucent (milky or opalescent or frosty looking). None of the photons entering the face of the translucent disc will be absorbed or changed in energy. They will, however, scatter many times and eventually scatter out of the disk, usually in a different direction than they entered.

The disc would seem to glow. If the disc is thin, the forward scattering would be strong and the sun could still be seen when viewed through the disc, although it would be surrounded by a halo of scattered light. As the disc were made thicker and thicker, the number of scatterings for each photon would increase, and soon the sun would no longer be visible, except perhaps as a "hot" spot in the uniformly glowing disc.

Thus, a thick disc of highly efficient light scatterers becomes a new "source" of photons, that are scattered from the disc uniformly in all directions. Since the incoming photons all came from one direction (the Sun), they have a net momentum that is applied to the disc upon entry, producing a light pressure force. However, since the exiting photons are emitted omnidirectionally, their averaged force on the crystal is zero. The net result is a light pressure force that is equivalent to the light pressure force that would be obtained if the photons were absorbed.

The number of emitted photons from the translucent disc is equal to the number that entered the disc, which is the area of the disk times the flux of photons from the Sun. The flux of the emitted photons at some distance R from the disc is then just the number of emitted photons, divided by the area of a sphere of radius R. This emitted flux drops off rapidly with distance, being roughly $1/4\pi$ =8% of the initial solar photon flux when the measurement distance is equal to the radius of the disc, and 2% when the measurement distance is equal to the diameter of the disc. In effect, the translucent disc has "blocked" the solar photon flux. Assuming the Weber Scattering Center Coherence Theory is correct, a similar effect should occur with neutrinos encountering a perfect crystal.

Discussion

It is a canonical belief in physics that a neutrino can pass through thousands of lightyears of lead before scattering; thus these reported experimental cross sections are "impossible," according to conventional neutrino scattering theory. As a result, experimentalists have reject J Weber's results out of hand and no one has attempted to repeat tne experiments. Some people have proposed a repeat of the experiments to various funding agencies, but their proposals have been rejected, usually after the funding agency program manager asked the opinion of neutrino detector scientists.

I think the many experiments done by Weber, especially the two recent experiments involving other people, show that given a strong enough source and a sensitive enough detector, that the Weber Effect exists. They have shown that a properly designed mechanical sensor can detect a nuclear reactor or the tritium in a warhead at a short distance. This is significant, since improved sensors can detect these sources at interesting distances.

What the Weber Effect is caused by is not known. The experiment with the 0.6 cm lead shield raises some questions that it might be X-rays from the tritium beta particles striking the wall of the sphere, but the estimated 0.5 to 1.0 cm thick steel wall of the sphere should have stopped the X-rays already. The Weber Effect needs further investigation. One way to proceed is to make a chopper wheel, a resonant detector, a blocking crystal, various shields for other particles, and repeat the experiments.

Expected Force

The force to be expected from the neutrinos interacting with the crystal cannot exceed the force that would result from the transfer to the crystal of <u>all</u> the momentum of the neutrino flux passing through the area of the crystal (if the neutrinos bounce back, as light does off a mirror, there could be an additional maximum factor of 2). The total force from a neutrino flux of S neutrinos per second per square meter of energy E incident on a crystal of cross sectional area A is:

$$F = SAE/c$$

where the speed of light $c=3\times10^{8}$ m/s. [For the computation of forces, it is useful to remember that one curie (Ci) equals 3.4×10^{10} disintegrations/s, one newton (N) equals 10^{5} dynes, and one electron volt (eV) equals 1.6×10^{-19} joules (J).]

For a 100 kilocurie (10^{5} Ci) tritium source like the one at LANL, the total neutrino production rate is 3.4×10^{15} neutrinos/s, and the flux at a distance of 0.15 m is $S=1.2\times10^{16}$ neutrinos/s$\cdot$m^{2}. I

would estimate the average energy of a tritium neutrino would be half the decay energy or E=18.6 keV/2=1.5x10^{-15} J. If the diameter of the crystal is 0.05 m (2 inches), the cross-sectional area is A=0.002 m^2, and the maximum force available would be F=1.2x10^{-10} N=1.2x10^{-5} dyne.

A single fission in nuclear reactor produces about 6 neutrinos carrying a total of 12 MeV in energy while releasing about 200 MeV or 3.2x10^{-11} J of energy as heat. For the nominal power level of a commercial reactor of 250 MW, there are 7.8x10^{18} fissions per second and 4.7x10^{19} neutrinos/s. At a distance of 100 m from the nuclear reactor core, the flux is S=3.7x10^{14} neutrinos/s·m^2. The average energy of the fission neutrinos is E=12 MeV/6=2 MeV or 3.2x10^{-13} J. For a detecting crystal of area A=0.002 m^2 the maximum available force is F=8x10^{-10} N=8x10^{-5} dynes.

The Sun is estimated to produce a solar neutrino flux at the Earth of S=6x10^{14} neutrinos/s·m^2. The average energy is estimated to be about E=215 keV=3.4x10^{-14} J. Using a crystal with the same cross sectional area of A=0.002 m^2 gives a maximum available force of F=1.4x10^{-10} N=1.4x10^{-5} dynes.

Thus, all presently available neutrino sources can give up to 10^{-10} N of force or more. More realistically, the actual force exerted on the crystals would be some small fraction of this, so it would be desireable to have a detector system that could measure 1% of this maximum force level, or 10^{-12} N.

Detection

Resonant mechanical structures like the gravity gradiometer[7] used by Grossi of SAO and Raytheon, the rotating gravity gradiometer (RGG) developed by Forward[9], and the Weber tuning fork, have a force sensitivity limited by thermal noise of the instrument that is given (within small factors of order unity) by:

$$F_T = (2kTM/\pi t t_i)^{1/2}$$

where k=1.38x10^{-23} J/K is Boltzmann's constant, T is the effective noise temperature of the structure (usually its physical temperature, but not always[9]), M is the active mass in the structure, t=Q/πf is the 1/e ringdown time of the structure with vibration frequency f and quality factor Q, and t_i is the integration time of the experiment (assuming proper data handling during integration, such as chopping the signal to eliminate low frequency drift noise).

If we assume typical parameters of t=10 s, m=0.1 kg, T=300 K, then the thermally limited force sensitivity of a resonant mechanical structure as a function of integration time t_i is:

$$F_r = (9 \times 10^{-12}\ N)/t_i^{1/2}$$

Thus, integration times of a few seconds to a few minutes is sufficient to detect force levels that are 1% of the maximum force levels from any of the sources discussed previously. Improved sensors can detect the same sources with shorter integration times or at longer range.

One obvious method for improvement, and the route taken by the SAO/Raytheon effort, is to cryogenically cool the instrument to liquid helium temperatures. At 4 K instead of 300 K, there is an improvement of 75 in temperature and 8.7 in force sensitivity. The difficulty in coping with cryogenic problems makes this approach a last resort.

A less obvious method for improvement is to decrease the mass of the sensing portion of the structure while increasing the neutrino capture cross-sectional area. The choice of an area for the crystal of 0.002 m^2 (2 inch diameter) and a mass of 0.1 kg (100 grams or 3.5 oz) for the crystal gives a thickness for the crystal of 2 cm. It can be made somewhat thinner (maybe a factor of 4 to 0.5 cm) without probably becoming too transparent to neutrinos. This factor can either be used to decrease the mass (although we soon run into the mass limits imposed by the structure needed in the detector to hold the crystal in place), or can be used to increase the area of the crystal and increase the signal level.

A simpler approach, and the first one to try, would be to increase the ring-down time of the instrument (effectively increasing the internal signal integration time), or to use a technique called "electronic cooling"[9], where the ring-down time is lowered from a high value while simultaneously lowing the "effective" temperature of the structure. Both depend upon obtaining a high Q factor in the mechanical structure. This is possible to do, but is a non-trivial engineering problem.

Experimental Verification of the Weber Effect by AL

Prof. Weber and Lt. Col. Lasche have seen a "booming" signal when a rotating crystal chopper wheel was used to convert the steady flux of antineutrinos from a nuclear reactor into a modulated flux that was detected by another crystal on a tuning fork. This type of instrumentation is relatively straightforward to construct and operate. If the Astronautics Laboratory were interested in independently attempting an experimental verification of the Weber Effect, they could procure a chopping system, resonant detector, and blocking crystals and carry out their own experiments, using as neutrino sources either the Sun or the 430 MW San Onofre nuclear power plant at San Clemente [the signal may even be observable from the Pacific Coast Highway].

One small business contractor with significant relevant experience in designing and building high sensitivity resonant mechanical sensors, who is ready to begin immediately on the design, fabrication, and delivery of such a system, is Mr. R. O. Newlon, Product Development Tech. Corp., P.O. Box 620934, Littleton, CO 80162 USA (303)880-3768.

Verification of the Weber Scattering Center Coherence Theory

Verification of Weber's theory is more difficult that the verification of the experimental Weber Effect. Assuming that the Weber Effect is found to persist, and testing with shields of lead, boron, and other materials have shown conclusively that the effect is not caused by any other particle than the neutrino, then the various parameters of the Weber Scattering Center Coherence Theory need to be varied in the experiments to determine if the signal strength observed varies with the parameters in the same manner that the theory predicts.

The N^2 parameter (where N is the number of scattering centers in the crystal) is the most sensitive and important parameter in the theory. The other theorists predict an incoherent scattering that goes as N, while Weber predicts a coherent scattering that goes as N^2. The large crystals presently being used in the experiments are too large to study this parameter, since multiple scattering is taking place in a thin layer near the entry surface. Thin perfect crystals with identical area, but varying thicknesses and varying N would allow this parameter to be varied. The equivalent amount of identical material, but in a glassy, polycrystalline, or amorphous state, should be used to back up the perfect crystal so that the mass and total number of atoms in the detecting apparatus stays the same, only the number N of "coherently communicating" crystalline atoms is varied.

An alternate approach to determine the variation in signal strength with N is to make a measurement with a thin perfect crystal, cleave the crystal into n pieces and reinsert them into the detector. If the scattering goes as N^2 (where N is the number of atoms that can coherently interact with each other through a perfect crystal), then the signal strength should vary as n crystals, each with cross-section of $(N/n)^2$, or a total scattering cross section of $n(N/n)^2=N^2/n$. Cleaving a crystal into 10 crystals should cut the signal by a factor of 10.

An additional alternate approach is to use crystals with varying amounts of imperfections. This would involve measuring the dislocation density in each crystal and correlating the signal level with the number of dislocations. The measurement of dislocation densities is a standard process in the semiconductor industry and can usually be obtained by requesting the measurement during the ordering process for the crystals.

Another parameter in the theory is the energy of the neutrinos. This parameter can be varied somewhat by using different sources. A tritium or other beta emitter neutrino source emits neutrinos with energies in the tens of keV, while for the Sun it is 100s of keV, and for a nuclear reactor it is 1000s of keV. It is conceivable that perfect crystals of varying materials and varying thicknesses could be used as "filters" to scatter the low energy neutrinos out of a beam, leaving only the higher energy neutrinos. A series of such filters with proper variations in composition, thickness, and spacing would extract out the low energy neutrinos left in the beam and scatter them omnidirectionally. Each successive filter (after the first) would then be a weak, but nearly monochromatic source of neutrinos.

Another parameter in the theory is the composition of the crystal. This could be varied by obtaining crystals of identical area, identical crystal perfection, and identical number of coherent scatters N, but with different atomic nuclei and different thickness (to maintain constant N if the density is significantly different). Some examples that might be obtainable as nearly perfect crystals (since they are semiconductor materials) are: silicon carbide, aluminum oxide, germanium, diamond, silicon, gallium arsenide, and indium phosphide.

Another parameter in the theory is the Debye temperature of the material. This is gives an indication of the inherent stiffness of the material. The Debye temperature of some typical materials are: diamond 2240 K, graphite 420 K, aluminum oxide (sapphire) 1000 K, silicon 645 K, germanium 374 K, and gallium arsenide 344 K. Since both diamond and graphite have the same composition (carbon), but significantly different Debye temperatures, measurements on perfect crystals of similar mass of the two materials would allow the stiffness parameter to be studied independent of composition.

To study many of the various parameters in detail in order to verify the Weber Scattering Center Coherence Theory, it would be desirable if the same apparatus were used for every measurement, varying only the crystals. It would also be advisable that the crystals be substituted in a "double-blind" fashion, where no one knows which crystal is which until after all the data has been reduced. One way to accomplish this is to design the experimental apparatus so that all the crystals have the same external appearance, shape, size, mass, and mounting points. These could include the crystals in the chopper as well as the detector, and could include the blocking crystals and the filter crystals if physically possible. One recommended approach is to design a standard "crystal can" of non-crystalline non-magnetic opaque material such as aluminum, with a standard size and standard mounting tabs. A typical size for the can could be 2 inches (5 cm) on the inside diameter and 1 inches (2.5 cm) deep, with an estimated total loaded mass of 150 gm. The crystal can would have

one face of the can designated the "front" or "entrance" face where the neutrinos first enter. The front of the can would be filled with the crystals to be studied, and the remainder of the can would be filled with spacers of plastic or dense glass or amorphous non-magnetic metal so that the total mass of each filled can is identical. The cans would then be sealed and marked with a randomly assigned code number that would be used to identify the contents only after the data had been taken and reduced.

Recommendations

Not knowing the "charter" of the newly reorganized Astronautics Laboratory, it is difficult to make strong recommendations concerning further effort on the Weber Effect, so I won't. If some of the long term possibilities outlined below fall into the categories that are of interest to the Astronautics Laboratory, then I recommend that you consider having a neutrino modulator and detector built, and carry out your own experiments using the Sun or a nearby power reactor to verify for yourselves the reality of the Weber Effect. Once the Weber Effect has been verified, then you can decide on the direction of your future research on the subject.

Since I am a former student of Weber, anything I say about the verification or non-verification of the Weber Effect would be looked upon with suspicion. Therefore, I should not be involved in the verification experiments except perhaps as a consultant on the fabrication and testing of the neutrino detector, since a resonant detector would be very similar to the rotating resonant gravity gradiometer structures I developed in the 1970s.

If the Weber Effect turns out to be real, and is found to be due to neutrinos, then it should be possible to develop a series of more and more sensitive neutrino detectors. In addition, by using the scattering crystals as neutrino collectors, collimators, filters, and modulators, the neutrinos from nuclear reactors (or even sealed canisters of radioactive waste), could be turned into powerful directional monochromatic modulated beams of neutrinos. These could have many applications, some of which might be relevant to future Air Force interests.

First generation versions of the neutrino detectors can sense nuclear reactors, including the reactors in nuclear submarines, at many kilometers. More sensitive second generation neutrino detectors can sense nuclear warheads or any radioactive fissionable material at some yet uncalculated distance.

Shields of crystals around our military sources of neutrinos could direct the neutrinos away in a safe direction and prevent our nuclear submarines or warheads from being detected.

Beams of neutrinos could be formed by collecting the neutrinos from a source by surrounding the source with crystals and then sending them out through a collimating hole in the desired direction. The beams could be modulated at MHz to GHz rates with crystals that are acoustically distorted into temporary crystalline imperfection. With these sources, line-of-sight communication systems using neutrinos become possible, even though the line-of-sight path is blocked by the earth or ocean.

Navigation using the neutrinos from the Sun, even when the Sun is on the opposite side of the Earth, is a possibility, but realistically there are better ways to navigate.

If the Weber Effect is found to apply to photons and other particles, then all methods of long range sensing and communication need to be reevaluated.

Unfortunately, the Weber Effect cannot be used for propulsion, except perhaps to get the last bit of push out of a nuclear rocket or an antimatter rocket by directing the neutrinos from the secondary reactions rearward to provide extra thrust.

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APPENDIX D

2020 A.D. TECHNOLOGIES FOR AFAL

Dr. Robert L. Forward

Space Transportation

- Rocketless ways to get to LEO
  - Guns - electromagnetic, Hertzberg ram accelerator
  - Rotating tethers
  - Pellet supported tall towers
  - Hypersonic airbreathing orbiters

- Rocketless ways to change orbital parameters
  - Sails
    - Solar pushed
    - Laser pushed
    - Atmospheric drag
  - Tethers
    - Electrodynamic
    - To and from heavy platforms
    - Momentum transfer to rotating tether "momentum banks"
  - Beamed Power
    - Microwave power to microwave plasma thrusters
    - Laser - thermal, sail, and electric
    - Pellet stream
  - Solar Thermal

- Non-orbital dynamics (multiple body with non-gravity forces)
  - Bouncing orbits with separating double-spacecraft
  - "Juggler" orbits with multiple tether "jugglers"
  - Zero delta vee transfers to lunar capture (JPL did already)
  - Transfer of momentum to tether momentum banks
  - Tether mediated multiple spacecraft interactions
  - Statites (non-orbiting in earth-sun system)

- Novel spacecraft
  - Microspacecraft (<5 kg.)
    - Design and develop
    - Unique missions
      - Base defense (original design)
      - Sensor arrays
      - Asteroid sampling
  - Gossamer Spacecraft (strings, nets, sails, balloons)
    - Design and Develop
    - Unique missions (see JPL and FUn reports)

Space Bases
- Base Defenses
  - Active - lasers, pellets, ECM, ?
  - Passive - armor, standoff "bumpers", wires, dust
  - Reactive - particle cloud 'beehive', magnetic
- Habitats (military unique)
  - Lunar
  - Orbital

Space Power
- Solar Power
  - Lightweight collectors
    - Inflatable
    - Unrollable parabolic concentrators (see Cal Space)
  - Multilayer solar cells (30-50% eff.)
  - Brayton and other thermal cycles
  - Solar pumped lasers
- Antimatter Power
  - Feasibility of antiproton factory at Edwards
  - Space qualified antimatter containers
  - Non-propulsion applications of antimatter
  - Design of antimatter powered power system
    - Thermal Augenstein reactor - Brayton cycle
    - Contained plasma MHD generator
    - ?
- Beamed Power
  - Coherent microwave, IR, or laser light
    - Rectify to dc (20 to 60% eff.)
    - Parametric conversion to ac (90%+ eff. poss.)
  - Pellets (with or without return)
- Ionospheric Laser Power (See Rasor Assoc.)

Space Resources
- Lunar Resources
  - Helium three mining
  - Manned, teleoperated, or robotic?
- Asteroid Resources
  - Find - add to modest university telescope searches
  - Identify - correlate ext. observables with internal comp.
  - Gather - rockets, mass drivers, sails and nets?
  - Process - solar, nuclear, grind to dust and sieve?

Space Operations
- Space Debris
  - Studies of seriousness to military missions
    - Moderate risk military missions vs. zero risk NASA
    - Effectiveness of standoff armor
  - Modeling of future growth and mix
  - Methods for control or removal
    - Dumb Area Sweepers - nets, sails, dust clouds, ?
    - Active laser or pellet vaporizers
    - Active "trash trucks" - ion drive or sails

- Unmanned Operations
  - Robotics
    - Autonomous construction of simple structures
    - Telecontrolled artificially intelligent robots
    - Autonomous AI robots
  - Teleoperations
    - LEO (almost instantaneous)
    - GEO (0.25 sec delay)
    - Lunar (2 sec delay)
    - Asteroids (many minutes delay)

- Spacesuits (novel-military unique)
  - Skintights with helmets
  - Cans with arms
  - One person deorbitable emergency rescue suit

- Sensors (unique military)
  - High res radar/IR/optical speckle interferometer arrays
  - Neutrino detectors for nuclear materials

- High Temperature Superconductors
  - Develop novel applications
  - Predict upper operating temperature
  - Design cryogenic systems for present operating temps

- Space Coatings (military unique)
  - Stealth
  - Laser proof
  - Thermal
  - Self-sealing

- Autonomous Navigation
  - Gravity gradient on non-spherical body
  - Pulsar triangulation

- Space Risk Analysis and Policy (military unique)
  - Don't let NASA no-risk policy dominate military needs.

(Launch Discovery right after Columbia explosion, with military crew, if payload is important to military needs.)

APPENDIX E

FUTURE BONUSES FROM OUR SPACE INVESTMENT

Dr. Robert L. Forward
Submitted to National Space Council 4 March 1990

INTRODUCTION

The two primary reasons for the United States of America to go into space are: to expand our basic knowledge about the solar system and the universe we live in, and to develop the technology that we will need in the future to utilize the known resources in space. Those reasons alone are enough to justify our investment in space, for over the succeeding decades and centuries after that investment has been made, the United States will reap benefits from that basic knowledge and those known resources to pay back the cost of the initial investment many times over. In addition to those known benefits, it is possible there could be future bonuses from space that we cannot now predict with certainty. Some of those future bonuses from our space investment are:

SOLAR STORM FORECASTING

A few times a year the Sun produces a violent explosion on its surface called a solar flare. Charged particles spurt from the flare out through the solar system. If the Earth is in the way, those charged particles spiral down the Earth's magnetic field lines and cause the aurora seen near the polar regions. In the past, the worst thing that happened was that short wave radio communication was cut off. The Sun is becoming more active and the Earth's magnetic field is slowly becoming weaker, allowing the charged particles to penetrate deeper and to lower latitudes. In the modern world, the survival of many of the world's businesses depends upon long distance radio communication through satellites, which can be damaged by those charged particles. More and more humans are flying high in the air over the polar regions in both subsonic and supersonic aircraft. Sometime in the future, it is possible a severe solar storm could give a serious radiation dose to a planeload of passengers. Our scientific investment in space will include setting up satellites to monitor the activities on the sun, including solar flares. Our technological investment in space will produce lightweight solar sails that can "hover" close to the sun, including "polesitter" spacecraft that sit over the poles of the sun. With this investment in space in place, we will be able to forecast the severity and direction of the solar flares and warn those on Earth to take proper precautions.

WEATHER MONITORING

The weather affects us all, from our personal inconvenience in rain or snow, to farmers whose decisions concerning irrigating crops or not can change a profitable year into a bad year, to commodity markets, to watershed managers, to air traffic controllers. The present weather satellites in the equatorial geostationary orbit have been of great help, but they cannot do a good job of monitoring the weather on the dark side of the earth, or in the polar regions, where all the weather starts. Once we have made our science investment in space on instruments that use special bands in the infrared and microwaves to monitor the ocean surfaces and clouds, then we can produce good weather maps in the dark. And once we have made our technological investment in space on solar sail propulsion, these solar sails can be used to levitate a weather satellite so it will continuously "hover" over the north or south pole of the Earth, monitoring the weather all around the polar regions at the same time. These "polesitter" spacecraft can also continuously monitor the ozone layer, which is of present concern to us all.

WEATHER MODIFICATION

Bad weather can cause serious damage. Hurricanes devastate islands and shorelines, jet stream changes cause floods or drought, changes in the composition of the atmosphere, especially increases in carbon dioxide and water vapor, can cause permanent global climate changes. A few decades ago, scientists were worried about a new "ice age", while today the concern is "greenhouse warming". Even a small storm contains large amounts of energy, more energy than the human race could apply to that storm. To modify the weather will require that we control large amounts of energy and apply it properly. Once we have made our scientific investment in space on gathering global information about the weather, we may find "weak points" in weather formation where the proper application of energy will change the weather more to our liking. And once we have made our technological investment in space on building large lightweight structures in space out of space materials from the moon and asteroids, we can build giant mirrors, to collect the ever present flood of sunlight in space and apply it to those weak points in the weather formations. Weather modification will not come soon, but one of these days, sunlight from the sky may dissipate hurricanes, dry up floods, and reorient the jet stream. If greenhouse warming becomes a problem, a large "parasol" in space between the Earth and the Sun can block a small percentage of the sunlight. If a new ice age threatens, a large mirror hovering in the sunlight high over the dark side of earth could provide heating.

ENERGY WITHOUT POLLUTION

A modern society needs energy. Yes... we can do a lot more to conserve energy, but there is an ultimate limit to that process. In the future we must have new sources of energy... new power plants. But what kind? Coal, oil, shale, peat, biomass, and other chemical combustion power plants produce pollution, especially carbon dioxide, a greenhouse gas. Nuclear and fusion power plants produce long-lived radioactive byproducts. Solar energy is a good answer, but each solar power plant on earth will use up many square miles of valuable land and many tons of metals and other minerals. Once we have made the technological investment in space on extraterrestrial materials, we will get the minerals from the asteroids, moons, and planets of the solar system, spread them out in the limitless expanse of space, collect the bounteous supply of solar energy flowing through space, and send the energy down to Earth. The ultimate goal would be to bring the energy down as concentrated fuel, like antimatter, or some other high energy density material. Perhaps it will be sent down on a high power superconducting transmission line that reaches from space to the ground. Until those technologies are developed, however, the power can be beamed down by lasers or microwaves. The beams will be directed at collectors in deserts and ice caps, where the electrical energy would be distributed using lossless high-temperature superconductors. As each new space power plant starts up, another Earth power plant can be closed down.

FREE FALL MEDICINE

We are only beginning to understand space medicine since all of our experience to date has been on remarkably healthy specimens of humanity. We don't know whether free fall medicine will be used only to keep astronauts healthy, or whether it can be a new form of medicine. There are some obvious examples where it would seem that free fall medicine would pay off immediately. Burn patients would suffer less if they didn't have to lie on their Earth-bound bed of pain. Multiple fractures would heal faster if they weren't being disturbed by gravitational forces acting on the damaged limb. Miscarriages may be less frequent if the mother's womb is not fighting gravity all the time. There may be other medical problems that would be helped by keeping the patient in free fall during the treatment program. Once we have made our science investment in space on space medicine, we will know what patients can be helped by free-fall and low-gravity environments. And once we have made the technological investment in space on reliable, low-acceleration methods of transporting fragile payloads into space, we can take seriously ill patients to orbiting variable-gravity hospitals where they can be made well again.

CONSERVING EARTH'S MINERAL RESOURCES

One of our major problems today is that a modern civilization needs buildings and machines. To make those buildings and machines requires lots of raw materials. To get those raw materials we gouge the ores out of the Earth, leaving terrible looking scars and mounds of ugly tailings. Once we have made our technological investment in space on extraterrestrial resource utilization we can mine the minerals we need from the asteroids, moons, and other airless bodies. Rotating tethers, solar powered mass launchers, and solar sails can move the minerals throughout the solar system. We won't need to use Earth resources to built our space infrastructure. We can even use rotating tethers or aerobraking to drop down refined chunks of hard-to-find or difficult-to-recycle minerals to the Earth's surface. Earth will no longer be an exploited slag heap, but a green park for mankind.

ASTEROID IMPACT WARNING AND DEFLECTION

Nearly one hundred years ago, in 1908, a modest snowball of a burnt out comet fell on Tunguska, Russia. It created an explosion equivalent to a 10 megaton air burst. The explosion flattened the forests over an area of one thousand square miles. Fortunately, no one was hurt, because no one lived there. If a similar comet struck today (or sometime in the next hundred years), the world would not be so fortunate. No one saw the comet coming, it was too small and was hidden in the glare of the sun. Even with all the comet watchers now active today, it is likely a similar sized comet head would be missed today. Even if the comet was detected, we could do nothing about it except try to evacuate the impact area. Larger bodies could cause more damage... perhaps even wiping out all the larger species of life, including us. Fortunately, the large events are very rare, but we can expect the small ones every few decades. Once we have made our science investment in space on orbiting telescopes and astronomical bases on the back side of the Moon, and once we have made our technological investment in new forms of space propulsion, such as nuclear rockets and electric propulsion, we can detect those incoming asteroids and get out there in time to cause a small deflection of those multiton bodies. If done soon enough, just a tiny deflection is sufficient to make the comet head miss the earth, skim the outer atmosphere, and sail back out into space. What could have been a major disaster would have been turned into an impromptu fireworks display in the skies.

GUARDIAN SECRETARY

Everyone, especially in their vulnerable developing years, needs a guardian angel. Every grownup could use a personal secretary. Once we have made the necessary technological investment in space on high power, high sensitivity communication satellites, then everyone can have a "guardian secretary". To achieve this will require more than just communication satellites in the equatorial geostationary orbit. They are too easily blocked by buildings or bad location. It will require new space propulsion techniques, like light-levitated solar sail communication satellites hovering at hundreds of positions all around the globe. Enough so that at least one comsat will be visible between the trees or through a window. What is now your wristwatch would become your guardian secretary, able to call anyone in the world with a single jump up to the space communication net, able to access any data source connected to that net, able to tell you which direction you are traveling, and where you are within less than the width of a freeway lane, and where you need to go. If your boss is looking for you because there is a new business contact to be followed up, he can find you. If you don't want to be found, turn your guardian secretary off. If you are 7 years old, lost in a woods, and it's getting dark, don't worry... your guardian angel will tell the police and your parents where you are. If those rough looking people following you are not those you wish to meet in person, punch 911. You are never alone if you have your guardian secretary.

SPACING TOXIC WASTE

The chemical factories and nuclear facilities that are part of making modern life possible produce toxic wastes. Some of the wastes can be used or processed into innocuous forms, but others are too difficult or expensive to deal with, and must be disposed of or stored somewhere. It has been suggested that toxic wastes could be disposed of in space, either dropped into the sun or stored away from humans on otherwise useless planetoids. At the present time, this option is not seriously considered, because chemical rockets are too fail-prone. Once we have made the technological investment in space on low-risk, high-reliability, low-cost, Earth-to-space transportation systems, this option for toxic wastes can be reconsidered. We can stop using the Earth as a dumping ground and put those toxic wastes far away from humans where they will cause nc harm.

SUPERSAVER SPACE HOLIDAYS

Nearly everybody would like to visit space... especially if there were a hotel at the other end with zero-gee swimming pools, quarter-gee ballrooms, and one gee workout rooms. They would also like holidays at hotels on Luna and Mars. The only problem is that the "airfare" is a bit steep. The reason that it costs a lot of money to go into space is that we use rockets. Rockets not only require a lot of fuel, but since they must carry all that fuel with them, the rockets have to be of lightweight construction, which makes them delicate, which in turn requires large ground crews to coddle them during takeoff and landing. Solar sails and rotating tethers are propulsion systems that don't use fuel. It will cost money to set them up, but once they are operating, they can be used again and again at no cost in energy or reaction mass. Once we make the technological investment in space on rotating tethers around the Earth, moon, Mars and other planetoids, we will have "elevators" that can pick up and deposit payloads from near space to any planetoid. Once we have made the technological investment in space on solar sails, we can travel rapidly between the planets in the solar system. No fuel needed, so no fuel cost. Travel into space will never be cheap, but those who can afford a trip to Australia today will be able to afford a trip to Perpetual Sunrise Hotel in low Earth orbit tomorrow. And those that can afford an "Around-The-World" cruise today, can afford a cruise around the solar system tomorrow.

ANOTHER FORM OF LIFE

There is only one form of life on Earth. From the simplest virus to the most complex mammal, all life on Earth uses the same genetic code, indicating that we all originated from the same primordial self-replicating organism. Because we know of only one form of life, our knowledge of biology and medicine is extremely limited. Our knowledge is <u>so</u> limited, that we don't even know how limited it is. Once we have made our science investment in space by looking for life forms on all of the planets and moons of the solar system, then we will either have found evidence for life, or not. Either result is significant. It may be that we find evidence of another form of life, either as fossils on Mars, primitive plankton in the waters under the frozen oceans of Callisto, or perhaps exotic bugs in the sulfur volcanoes of Io or the high pressure hell of Venus. If that life form uses the same genetic code as we do, then that means we are related somehow, perhaps seeded by the same comet from another solar system. If the life form is drastically different, then our biologists and doctors will have to stretch their theories to accommodate this new form of life. In the process of stretching their theories, they may learn more about our form of life. It may be that no life is found anywhere else in the solar system. That will only make us more appreciative of how precious life is here on Earth.

TO THE STARS

An ancient dream of mankind has been to travel to the stars. Our gigantic leaps into space are but our first steps on the way to those stars. Once we have made the science investment in space on orbiting infrared telescopes and large observatories on the back side of the moon, we will be able to find and study planets around the stars that lie nearest to the sun. And once we have made the technological investment in space on large power plants and laser propulsion, then we can start planning to visit the stars. A large power plant in space that sends a beam of microwave power down to Earth can be used (during its preliminary test phases) to push a lightweight spacecraft to the stars at 20% of the speed of light. The probe would fly through the three-star Alpha Centauri system and send back television pictures 25 years after it left. If the probe found something interesting, we could then use high power lasers to push a gigantic lightsail carrying a human crew to 50% of the speed of light. By proper design of the sail, the crew could be brought to a halt at Alpha Centauri, explore the planets there, and return in less than a human lifetime. The mission will be difficult and expensive using known technologies, but it is expected that our investments in space will find better ways to accomplish interstellar travel. Even without developing new technologies, however, once we have made our planned scientific and technological investments in space, if we want to, we can use those investments to go to the stars and back before the 21st Century is out.