

SUMMARY OF THE CONFERENCE SESSIONS

I. SPACE POWER AND ENERGY

Chair: Peter Glaser

Summary: David Criswell

It is a real pleasure to participate in *The High Frontier Conference*. One of the great things in my life was to work with Gerry O'Neill from 1975 to 1983. This is the first conference I've attended since then and it's really been a wonderful opportunity to meet old friends, make new ones, and learn of the interesting work supported by the Space Studies Institute. The members and staff of the Space Studies Institute are to be congratulated for carrying on both O'Neill's spirit and quest by supporting many significant research projects, working groups, and conferences such as this one.

During the past twenty years another wonderful thing that's happened to me was to be acquired by six grandchildren, two of whom are little girls born within the past few months. It's interesting watching an infant grow. At first the child doesn't know it exists. Then, it becomes increasingly self-aware. It is a marvelous process to observe. But, if our eyesight were at the level of a microscope self-awareness might scare us. I remember reading, just a few weeks ago, that five percent of your body mass is bacteria. Suppose that as you look at the infant you don't see the infant as a person. Rather, you see all the myriad of cells that make up the infant. You would see them cooperating in very complicated, extremely intricate processes that we don't understand but that produce the small human. Self-organization of cells and infants from chemical elements and the energy of their food is a primary mystery.

I've been fascinated by how cells cooperate to make more complex beings ever since I read "The Lives of the Cell: Notes of a Biology Watcher" by Lewis Thomas. He was a physician, NIH program official, and a scientific poet. Reading Thomas and watching children become aware makes you realize that our grand thoughts and goals for human migration into space well up from multi-trillions of very small, individual self-functioning cells which, for some reason, tend to cooperate. In a way, this energy session deals with starting on the "cellular" level of technology and building up to larger, more complex, and self-aware systems that eventually will enable human life and it's cells to spread far beyond Earth.

Three of the *Space Power and Energy* papers focus on the cellular level of technology. Dan Brasoveanu (Computer Sciences Corporation) presented "Application of Functional Time-Based Satellite Telemetry." It deals with taking information, at just above the noise level, from a very wide range of inputs, and extracting the essence. Brasoveanu investigates the mathematical basis of the process and is applying the method to reducing the cost of energy on a satellite of

transmitting the core information to Earth. Spatial awareness is crucial to many aspects of space flight. Po Kee Wong, with co-authors Adam Wong, and Anita Wong, discussed their formulation of how to best describe the relative positions and motion of spacecraft relative to tracking stations on Earth and to each other in the paper "Application of the trajectory solid angle (TSA) and the Wong Angles (WA) to solve problems of THAAD for BMDO and for future missions of NASA." They emphasized procedures published primarily in United States patents.

Arthur C. Clarke rewrote only one published story, his 1948 "Against the Fall of Night," as the 1956 novel "The City and the Stars." Clark proposed that the perfect machine has no moving parts. My experience with machinery (in cars, planes, houses, computers, electric distribution systems and power outages, etc.) convinces me that Clark was right. John Cable, of The Mars Society, gave a very interesting talk on the "Integration of Thermoacoustic Stirling Hybrid Engines and Regenerative Fuel Cells." The Thermoacoustic engine actually uses acoustic waves in a gas as the power component. The fuel cell used ions moving through membranes and solutions. While these two devices do use the movement of individual molecules and atoms, they are much closer to Clark's concept than are flywheels, turbines, or piston engines. Both may enable higher reliability power systems that are required for long duration flight beyond Earth.

Going back to Lewis and "The Lives of the Cell," the regenerative fuel cell might be associated with mitochondria in the cells of our own body. Some researchers have argued that mitochondria are derived from the evolutionary path that produced chlorophyll. Chlorophyll is the molecule that captures sunlight and thereby energizes the creation of new life and the maintenance of Earth's biosphere. Half of Earth's new biomass is produced in the oceans, and half on land. Oceanic biomass is consumed quickly in the fishery food chain or lost to the ocean depths. Very little is stored. On the land the new biomass is created primarily as new tree growth. Suppose that all the new land-biomass were harvested for one year and then dried. If that biomass were then burned steadily over the course of a year it would yield approximately 50 terawatts of thermal power ($TWt = 1 \times 10^{12}$ Watts of thermal power). Why is that relevant to space power? First, the new biomass was generated by sunlight. Burning one year of land-biomass is a very inefficient and destructive way to obtain 50 TWt of solar thermal power. Second, the world now consumes approximately 14 TWt of commercial power primarily by burning fossil biomass (coal, oil, natural gas). World commerce is depleting this fossil biomass at an accelerating pace. Third, in the year 2000 the World Energy Council, which is composed primarily of the energy agencies of most of the nations and the major energy corporations, proclaimed that within two generations everyone on earth should be provided ~ 7 kWt per person. This goal is driven by the desire of the poor developing nations, which use less than 2 kWt/person, to achieve power parity with the rich developed nations, which use 7 kWt/person or more.

Providing 10 billion people with 7 kWt/person implies a global commercial power system with 70 TWt of capacity by 2050. Clearly this goal cannot be met using land-biomass that yields only 50 TWt. Also, a prosperous world will use the order of 7,000 TWt-years of energy per century.

This means that a prosperous world would consume all the fossil fuels early in the 22nd century. It is a very big challenge to provide adequate, clean, and affordable power at the level of 7 kWt/person or the electric equivalent of 2 to 3 kWe/person. The bio-technology of chlorophyll, even after 3.8 billion years of evolution, is not adequate. The inadequacy of chlorophyll is why Glaser's concept of the space solar power satellite and the microwave beaming of power to Earth is critically important to the progress of humankind. The beams of microwaves are converted on Earth by rectenna elements, essentially small TV antennas across a diode, into commercial electric power. The rectenna elements are the commercial power industry's equivalent of chlorophyll. However, rectennas are hundreds to thousands of times more efficient than are trees, algae, or grasses in converting sunlight into commercial energy.

Unfortunately, many people are more fearful of low-intensity beams of microwaves than of sunlight. This is why the lunch-time presentation "Electromagnetic Fields: Think benefits, not hazards" by Eleanor Adair (US Air Force Research Laboratory) is important. [For additional information refer to - Kolata, G. (2001, January, 16) A conversation with Eleanor R. Adair - Tuning in to the Microwave Frequency, New York Times, Section: Health and Fitness, D7.] Eleanor Adair is one of the world experts on the interactions of living matter, especially animals and humans, with microwaves. She told us that we should not be fearful of the transition of commercial power from fossil fuels and biomass to electricity supplied by microwaves from solar power facilities in space. Microwave beams operating at 10 to 15 centimeters wavelength pass through the atmosphere, rain, snow, fog, dust, animals, and humans. An adult human adsorbs only one percent or so of the beamed power as heat. Ninety-eight percent or more of the microwaves pass through with no effects. For low-intensity beams, $< 100\text{s of Watts/m}^2$, an animal or human simply rejects the heat of the absorbed microwaves just as the body rejects the much larger flux of heat that it normally produces. In contrast, sunlight photons are efficiently absorbed by the topmost millimeters of skin to produce physical burns, breakage, and random coupling of DNA and proteins, and other damage. Based on her many decades of work, Adair maintains that microwaves are so decoupled from us, and for most living systems, that we can safely incorporate microwave power beams as a new source of fundamental commercial power energy. Microwave power beams from space power facilities can enable the growth of an advanced civilization on Earth that is essentially decoupled from the energy and material flows of the limited biosphere. By supplying 20 TWe to 30 TWe to Earth from space solar power facilities, a world of 10 billion people can have a higher level of prosperity than the developed world now enjoys. This newly prosperous world will have the clean energy and wealth to restore the biosphere to a pristine state.

In his opening remarks to this session on Space Power and Energy, Peter Glaser (retired - A. D. Little) reviewed the SSPS concept and the human needs for clean and abundant power. The book *Space Solar Power Satellites* (Ed. Glaser, Davidson and Csigi, 1997) contains thirty papers on the major facets of space solar power. NASA conducted two extensive studies in the 1970s (~20

M\$) and late 1990s (~27 M\$) of the Glaser concept for space solar power satellites that would be deployed from Earth and operated in orbit about Earth.

Dan O'Neil (NASA - MSFC) presented results of the 1990s "New concepts and technologies for NASA's Space Solar Power Exploratory and Technology Program" for the program manager Joe Howell. This "Fresh Look" examined new architectures for relatively small payloads of components that could "self-assemble" in orbit about Earth and then self-transport to a higher operational orbit. "Fresh Look" was extended to consider the application of high-power technology to interplanetary spacecraft, extremely large communications satellites, new Earth-to-orbit launch systems, and advanced materials and systems. Both the 1970s and 1990s studies determined that power satellites were technically feasible. However, they both projected high cost for the commercial electric power to be sold on Earth. Also, both the 1970s and 1990s studies considered relatively small fleets of satellites that would provide only an incremental increase in the capacity of the global power system.

High cost for power from satellites deployed from Earth is to be expected. It is extremely expensive to build devices on Earth that are to be deployed in space and then maintain and repair them. It is expensive to send things up from Earth and to deploy then in orbit about Earth. One kilogram of satellite mass (original and maintenance mass) is associated with the delivery of ~10,000 kWe-h or electric energy to Earth. To significantly accelerate the economic growth of developing nations, the energy should be sold for less than 1¢/kWe-h. This implies a cost of less than 100 \$/kg for the satellite and all associated systems. Expenditures on R&D, component manufacturing, rectenna production and maintenance, interest payments, and other ground expenditures will account for most of the \$100 and likely leave less than 20 \$/kg for launch of the one kilogram of satellite and space operations over a 30 to 50 year life cycle. Launch costs of 20 \$/kg are the order for the price for a first class flight (passenger and luggage) between New York and London. In the mid-1970s O'Neill argued that materials could be supplied from the Moon to build at least 90% of a solar power satellite. Approximately 2 M\$ was expended by NASA in the late 1970s examining this option. Cost for a relatively small fleet of lunar-derived power satellites, ~0.3 TWe, were projected to be similar to that of power satellites deployed from Earth. Deploying components from Earth or bulk materials from the Moon violates a fundamental principle for the production of industrial commodities: minimize the number of operations to build and maintain the product.

In the late 1970s Bob Waldron (retired from Rockwell Downey) and David Criswell (Un. Houston) conducted studies on the conversion of common lunar soils and rocks into materials such as glasses, ceramics, metals, and chemicals that engineers could use to build and operate a wide range of industrial machinery and final products. Following these studies we realized three basic things: First, there is no need to build large satellites to collect solar power. The Moon exists, and it dependably collects 13,000 TW of solar power. This is far more than the 20 - 30 TWe that is needed by a prosperous world. Second, we realized that all the things that make the

Moon inhospitable to humans (no air, no water, dry, mechanically still, extremes of hot and cold, etc.) make it ideal for the large-scale collection of solar power. Third, all the resources exist on the Moon that are needed to build the large-scale systems for solar power collection and the transmission of microwave power. In "The Lunar Solar Power System, biospheric-independence, and the emerging two-planet economy" Criswell explored how to develop commercial solar power systems on the Moon. In an approach compatible with the 1970-80s NASA and O'Neill studies, all facilities, production machinery, and people can be deployed from Earth and then use lunar materials to construct solar collectors and power-beaming systems. To provide the world with 20 TWe by 2050 requires an upfront budget over ten to twenty years, comparable to the budget of the United States Department of Defense. Much of the DoD budget is now devoted to protecting energy supplies for the developed nations and protecting the developing nations from attacks by hostile groups in poor nations. For delivery of energy to Earth, this 1980s style LSP approach is projected to be ~1,000 times more efficient in its use of mass deployed from Earth than deploying SPS components directly from Earth or from the Moon. Advances in the automation of industrial production, teleoperation of remote machinery, and use of lunar materials to build most of the machines of production (i.e. - bootstrapping) can further decrease the mass deployed from Earth by at least another factor of seven to ten. Upfront cost would be reduced to that now associated with government space programs. An LSP industry on the Moon and in cis-lunar space can also build very large spacecraft that would be impossible to launch from Earth. Large spacecraft can enable humans to safely explore and develop the solar system at relatively low marginal cost. Access to lunar materials and solar energy enables humans to grow the first living systems beyond Earth.

Douglas Witherspoon (Advanced Launch Concepts) and Christopher Faranetta (UTRON) provided an especially exciting presentation on the "Wireless Power Project." They introduced the solar power satellite concept to high-school students. They use space solar power to teach students about the dependence of the Earth on solar energy, the concepts of energy and power, the future possibilities for humans to control their own destiny, and to increase interest in science and mathematics. They received special recognition and an award at the SSI banquet. Over the past few years I have responded to emails from high school students around the world wanting to know more about solar power satellites and the moon. I see this as young individuals struggling to become aware of the larger possibilities available as society thinks beyond its cradle of Earth. Witherspoon and Faranetta are providing the educational tools to accelerate the growth of this larger awareness.

Successful living organisms spread to new realms. Going beyond Earth in a reasonable time, especially beyond the solar system, requires propulsion systems of enormous power and low mass compared to those now available. G. A. Smith (Synergistic Technologies), K. J. Kramer, and K. J. Meyer (Pennsylvania State University) presented their concept for "Antimatter-initiated microfusion: Missions and systems studies for exploration of deep space." They reviewed the

status of successful experiments to produce and store tiny quantities of antimatter and the designs of rocket engines that could utilize large masses of antimatter for both interplanetary and interstellar missions. Eventually the human race will travel to the stars. To do so, the human race and its machine co-workers may have to tap a large fraction of the power of the sun for the industrial-scale creation of antimatter and the establishment of power beams that extend far beyond the solar system. It is highly likely that massive solar power satellites in deep space, far beyond Earth, will be required. When this happens, a future Lewis Thomas' "The Lives of a Cell" will have a new chapter. It will explain how self-aware human/machine systems have expanded to vastly larger systems that directly tap Sol and enable humankind to range far beyond the solar system.

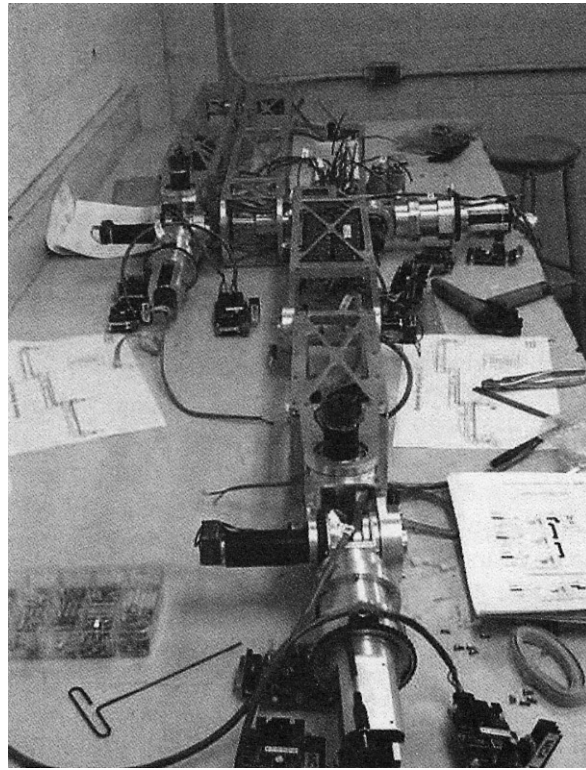
II. ROBOTICS

Chair: Red Whittaker

Summary: DeWitt Latimer, IV

From the Canada Arm on the ISS to rovers on Mars, robots are poised to make significant contributions to the space development. The space community looks to robots as explorers, precursor builders, and aids to human development of space. Recent setbacks, such as the Mars polar missions, have demonstrated the need for further research into the software that operates these complex tools. Papers in this session present ideas to enable robots to accomplish these tasks while building the fundamental science of autonomy to increase their capabilities.

Walking softly to build the infrastructure of space was the theme of Sarjoun Skaff's presentation on Skyworker. This robot, designed as much by machine as by humans, was built by Carnegie Mellon University's Robotics Institute. The Skyworker project spearheads autonomous assembly, inspection, and maintenance concepts for space solar power facility construction. Skyworker is a three-handed manipulator robot meant to address necessary high-orbit construction tasks that would be too dangerous or expensive for astronauts to perform. Skyworker operates like a waiter carrying a heavy tray, balancing heavy payloads while walking underneath. The research includes an analysis of the robotic workforce necessary to build full-scale space solar power stations tens of square kilometers in dimension. Not just the final Skyworker robot, but hundreds of thousands of candidate robot designs were automatically generated, simulated and measured against metrics such as the time to complete the task and energy consumption. Skyworker represents the most recent addition to the family of robots that will be needed to construct these space solar power facilities.



Skyworker, under construction at the Robotics Institute, Carnegie Mellon University

Techniques for coordinating teams of heterogeneous robots, proposed by Trey Smith from Carnegie Mellon University's Robotics Institute, addresses the big picture of robotic teamwork for construction in locales such as Mars. Three robots are utilized: a crane, a robot with a dexterous hand, and another robot with cameras. The robots cooperate to perform one of the primary tasks to be undertaken in any form of space construction, inserting a beam into a fixture. The primary obstacle to robotic development of space is not mechanical capabilities, but the software methodologies to develop the intelligence robots need to carry out their tasks. Smith characterizes the issues in the development of reliable, intelligent, autonomous systems based on his development of cooperative robots.

DeWitt Latimer of Carnegie Mellon University's Robotics Institute & Civil Engineering Department presented a survey of the state-of-the-art components needed for mining on planetary bodies. The review examines promising technologies for mining excavation in terms of planning, monitoring, digging, moving and processing ore. The study's conclusion agrees with Smith: that although the component technologies already exist, there is a need for overarching software engineering to develop a fully autonomous system.

The concept of robots as the near-term explorers is given a boost by the presentation of Hyperion, an energy conscious robot that plans its missions around the availability of sunlight as

a power source. Red Whittaker discussed this current project of Carnegie Mellon University's Robotics Institute in total system design and development. Until now, many robots that used solar power only have done so inefficiently. Mission planning often interfered with optimal solar energy collection. This summer, we will take Hyperion to Devon Island, near the Arctic Circle, and turn it loose. It will plan its path to angle its solar cells optimally to receive power from the Sun. This is a significant step forward in energy resource utilization for robots.

Richard Blomquist, of Carnegie Mellon University's Robotics Institute, takes robots away from planetary surfaces, away from space structures, out into the solar system. The Solar Blade project is a nano-spacecraft (seven kilograms) propelled by the light pressure from the sun. This craft is a heliogyro with four 40-meter long solar sail blades. This technology enables high delta-v missions such as polar surveying of the sun, asteroid and comet rendezvous and maintaining a stationary position over Earth's North Pole.

James Dunstan of Lunacorp Inc. presents work in using robots to bring the experience of space to everyone. One goal of space advocacy is to help motivate people, especially the younger generation, to identify with space and to desire to go there. The use of robots in an immersive telepresence game application is one solution being developed at Lunacorp to bring the abstract concepts of space into concrete form.

III. LIVING IN SPACE

Chair: Peter Eckart

Session 3, about Living in Space, was quite a diverse session, discussing a variety of different subjects. The session showed that we have visions, that we know where we want to go and what we want to do. The main issue now is to get somewhat more specific by investigating the research areas and problems associated with Living in Space in more detail.

We started with a presentation by Professor Komerath of Georgia Tech, who discussed how to actually construct a radiation shield for a space colony with a radius of one kilometer. The situation here is that we have the intention to build colonies in space and that there are concepts for the delivery of the construction materials, for example, by using mass drivers to bring materials from the Moon to one of the libration points of the Earth-Moon system. However, we do not know exactly what the actual construction process for these space habitats should look like. Professor Komerath presented a concept where the entire habitat structure is basically build around the grid of a cylindrical structure. He discussed quite some details of the construction process of this concept. This is certainly the kind of detailed study that we need now: once we know what our colony or habitat is going to look like, we have to define the assembly sequence and then ultimately install it.

The next presentation by Dr. Paterson covered the Gaia Hypothesis and was more of the philosophical kind. His point was that humankind should try to bring Gaia, the biosphere of the Earth, out into space. Dr. Paterson considered this a necessity and the only way that we as a human species can survive out in space.

The session went on with quite a challenging presentation by Bruce Mackenzie, who talked about the rationale of a one-way (!) human mission to Mars. This presentation did not only provide many details about Mars mission plans and mission sequences, but it cumulated in the very challenging question whether it is actually necessary to bring a human Mars crew back to Earth. Mackenzie argued that the strategy of installing a permanent settlement would help to avoid a 'Mars-Apollo'-effect, where all future plans might be cancelled once it has been proven that humankind can land people on Mars and bring them safely back to the Earth.

The next presentation in the session was by Professor Jewell of Cornell University. He discussed how to design a water management system for closed biosystems in space. Using numerous schematics and charts, he pointed out how difficult it is to achieve a mass balance in a closed ecosystem. This is mainly due to the fact that many elements and many loops are involved in such a system. In the discussion, Lee Valentine of SSI pointed out that the real key issue, as identified in the preliminary studies, was to achieve a balance of the nitrogen loop. Once this problem was solved, the research group felt confident that a robust water management system will be available within a few years.

The final two presentations dealt with the Moon and the development and design of lunar bases. First, Robert Howard of the University of Tennessee discussed the rationale and objective of going back to the Moon. Starting out in 1958 and asking the question why NASA was originally formed, Howard introduced the basic contents of the National Space Act and reminded the audience that the bold space endeavors we would like to see NASA conduct are actually part of its purpose. However, there is obviously a current lack of commitment with respect to specific human missions, such as the installation of a lunar base a mission to Mars. Next, Howard presented rationales and objectives for human for human space exploration and distilled some basic requirements out of these, in particular for a human mission to the lunar South Pole.

The session chair, Dr. Peter Eckart from the Technical University of Munich in Germany, concluded the session by elaborating on the different technologies required for lunar base installation, most of which could also be applied for a Mars base. After presenting the different technologies, he made the point that although requirements are currently very well defined, still a lot of theoretical and experimental work needs to be conducted before these technologies are ready for installation on the surface of the Moon or Mars.

IV. TRANSPORTATION

Chair: Leik Myrabo

This session encompassed six papers on transportation. The first four addressed Earth launch and in-space propulsion systems, and the last two involved Mars missions.

The first paper, entitled “Rocket Propulsion Technology Impact on TSTO Launch System Cost,” was given by Jason Mossman. The work summarized a systems analysis study of unmanned, two-stage-to-orbit vehicles (an 'orbiter' and a 'booster') with four different combinations of propulsion systems. The specific application was to deliver a 12,000 lb. payload into polar orbit. The aggressive mission model assumed at least one flight a week, with payloads having very simple interfaces to permit rapid integration with the launch vehicle. The operations concept required the vehicles to be launched vertically, from a simple pad, and that the booster and orbiter would be fired in series at the optimal staging velocity. The booster would be flown back with hydrocarbon-fueled turbo jet engines to the launch site for a horizontal landing; likewise, with the orbiter. Both are then taken to a post-flight processing facility. One interesting conclusion of this detailed launch system cost study was that hydrocarbon-fueled vehicles showed a strong advantage over the comparable hydrogen fueled stages. In general, they were smaller, weighed less, and apparently had lower recurring costs than the hydrogen fueled option.

The second paper, given by Derek Tidman, was entitled “Progress on the Spiral Slingatron and its Possible Development Path.” Derek gave the audience an update on the new developments accomplished since his previous SSI presentation two years ago. And there was a lot to report. Basically, the spiral Slingatron is a simple mechanical device that is able to accelerate a continuous stream of projectiles to high velocity. Derek proposed a range of defense, industrial and more ambitious space applications for the unique launch concept. More than half of the presentation addressed the theory and mathematics of his system. During the last 10 minutes, Derek showed 3-D computer aided design drawings, as well as computer animations of the Slingatron in operation. In one system, Derek examined the potential for launching kilogram-class payloads, with conventional drive-motor technology employing a large 747-class turbo-shaft engine. Judging by the number of comments and questions coming from the audience, all of us would have liked to see much more time spent on these animations, with further interpretation by Derek. Lots of interest was expressed in the launch concept.

Yours truly was up next, giving a report on “Beam-Propelled Lightcraft and Lightsails: Latest Developments.” About six months after the last SSI conference in 1999, I was fortunate to secure Jet Propulsion Laboratory/ NASA sponsorship to demonstrate the first major photonic thrust measurements for a real laser sail material in a vacuum environment. The pendulum deflection tests were performed on a 150 kW carbon dioxide, LHME laser at Wright Patterson AFB, and measured a thrust of 3 to 13 dynes per watt (with laser powers of less than 12 kW), on 5-

centimeter laser sail manufactured by ESLI in San Diego, California. These are carbon microtruss fabrics, were a couple of millimeters thick and were sputter-coated with molybdenum. They took enormous abuse from that laser and survived operating temperatures up to 2400K. Exactly one year later, in December 2000, I returned to the LHMEEL facility to attempt to propel even more exotic laser sail specimens, vertically up a wire using laser power levels up to 55 kilowatts. The new laser sails had a layer of carbon foil on the front side (still molybdenum coated), and reinforced on the backside with the same carbon microtruss material used in the Dec. 1999 experiments. My students and I are still analyzing the data from these flights, using sophisticated motion analysis software. I finished up the talk with a brief review of my 2 October 2000, FINDS-sponsored laser-propelled Lightcraft flights at White Sands Missile Range. We set a new World's altitude record of 233-feet, using the ARMY's 10-kW pulsed CO₂ laser, called PLVTS. This laser Lightcraft technology is easily scaleable, and it's just a matter of building larger lasers to lift larger and heavier payloads into the sky.

Our next paper was given by Boris Guirchovitch, and entitled "Assessment of the Minimum Duration for the Spacecraft Attitude Maneuver." He addressed the problem of evaluating the minimum time spent performing an attitude maneuver, a rotation, in the vacuum of space — for docking and undocking processes or just prior to an orbital correction 'burn.' So imagine a Soyuz capsule, or some other spacecraft, coming up to the space station docking port, and performing the exact attitude-adjustment maneuver, with minimum expenditure of propellant. Basically, the spacecraft body is moved from its initial position to the final, by a single rotation about an axis of finite rotation. Boris considered this as a kinematic and geometrical problem, and solved it without any numerical integration, which might seem to be a more sophisticated method of accomplishing the same result. However, his method is very attractive because of its simplicity. His solution for the attitude maneuver gives the minimum variation along with the maximum angular rate and acceleration. Boris said says his numerical results can be derived with an uncomplicated procedure with several equations and two tables.

Our next presentation, entitled "Frequent, Fast Trips to and from Mars via Astrotels" was given by Kerry Nock. His concept for an interplanetary rapid transit system architecture was funded by the NASA's Institute for Advanced Concepts (NIAC), and basically would reduce Earth/Mars human trip times to just 5 months. The system architecture employs small, solarelectric-propelled, highly autonomous, space ships (dubbed 'Astrotels'), and hyperbolic rendezvous (between them and the planetary transport hubs) —using even smaller, fast-transfer, aeroassist vehicles that Kerry calls 'Taxis.' The Astrotels would operate in cyclic orbits between Earth, Mars and the Moon. The Taxis would fly rendezvous trajectories between the cycling Astrotels and transport hubs. Kerry said his effort was based on a National Commission on Space study (carried out 16 years ago), and provides a vision of a far off future that establishes a context for near-term technology advances.

The final paper of the session was presented by Boris Berkovski: “An Inflatable Wing-in-Surface-Effect Vehicle for the Exploration of Mars.” Boris proposed a novel vehicle, dubbed the 'inflatable Ekranolet,' as a cost-effective and efficient solution to the problem of long distance transportation on the surface of Mars. The objective is to take advantage of the high aerodynamic efficiency, and simple storage requirements of a large inflatable airframe. Boris envisions cruise speeds of 250-300 mph and ranges of 2000 miles —with the wing in ground-effect over the Mars surface. He proposed a family of vehicles with long-range manned, long-range robotic, and short-range robotic missions. Boris identified five specific applications for the inflatable Ekranolet, including 1) performing high resolution geophysical surveys; 2) delivering remote weather, seismic and compositional measuring instruments via airdrop or landing; 3) performing detailed atmospheric measurements; 4) providing detailed photographic maps of proposed surface rover routes; and 5) delivering supplies to rover crews. The audience seemed genuinely intrigued with the inflatable Ekranolet concept itself, as well as with hearing the fascinating history of very large wing-in-ground-effect vehicles in Russia.

Well that about wraps it up. We had a very interesting collection of papers in the Transportation Session this year.

V. ASTEROIDS AND SPACE MANUFACTURING

Chair: John S. Lewis

We'll be proceeding in quasi-numerical order. This brings us approximately to Session 5, which was Asteroids and Space Manufacturing.

The first paper on schedule was a report on the Spacewatch program involving Bob McMillan and Tom Gehrels, who were unable to attend the meeting because of exhaustion of their financial resources. I've asked Lee Valentine to read Bob's brief written description of his progress. That description is so vividly familiar to me that I hesitate to start reciting it for fear I'll tell you too much. The core of it was a summary of the various achievements of the original 0.9 meter Spacewatch 1 telescope and a summary of progress on the 1.8-meter telescope for Spacewatch 2. As you're undoubtedly aware, the entire near-Earth asteroid discovery business has accelerated dramatically in the last few years and shows every sign of being now at its maximum possible discovery rate. That implies having discovered approximately 50% of the entire population of large near-Earth asteroids. The rate of discovery of kilometer-sized NEAs is expected to fade off over the next year or two. The total rate of discovery of asteroids, though, including those smaller than one kilometer, may not decrease for some time yet, because those populations are huge and very hard to catalog fully.

The second paper of this session was presented by Bob Strong, "Update on the Development of a Near-Earth Object Observatory and its Role in Education." At the risk of telling you too much about this project I shall briefly summarize the report. With the assistance some volunteers, including some avid astronomers and some people whose principal skills are in construction, they have made a good start on the first shed to house their telescope. They have also succeeded in identifying a promising second location for placing these telescopes. I think the most astonishing aspect of what he has done is the ratio of accomplishment to salary money, which I believe is infinite. It's an unusual state of affairs. Bob has had the good taste to name the observatory after Arthur Clarke, a maneuver appreciated not only by Sir Arthur but also by, I think, every individual here. This progress undoubtedly will continue, with much more to report two years from now. So, congratulations on your progress and best wishes for the next couple of years.

The third paper in our session was given by Dave Kuck, again a long-time participant in these conferences. He talked about the interesting and novel application of the technology of arc jet propulsion, which was actively researched in the 1960s, and then, like almost everything else in the realm of advanced propulsion technology, has been severely neglected by NASA since that time. Their neglect of solar sails, plasma jets, arc jets, ion engines, solar sails, solar thermal engines, and so on, constitutes a nearly complete catalogue of all the promising propulsion technologies there are. What Dave has done is to apply the principle of the arc jet or plasma jet to steering, maneuvering and recovery of iron-rich near-Earth asteroids where the propellant is wisely chosen to be the material on hand. His description was rendered especially vivid by the pictures of actual plasma jets in action. This technology is likely to be in a relevantly forgiving one, in that, unlike an ion engine, we don't have to worry about the degradation of the pull-out grid and the short operational life times of high voltage power supplies that are the required. Everything can be operated in a relatively simple geometry and with relatively few moving parts. There's some hope that this can be made to work on a modest scale. Dave's presentation concentrated on small asteroids with a value of millions of dollars because they're obviously vastly easier to move around than the bigger ones.

The next paper was written jointly by Tom Taylor and Bob Strong. The title is "Human Species Survival in Large-Impact Events." We actually heard the necessary background for this paper here at this session two years ago where Tom presented a rather detailed account of how he would go about hollowing out the core of a long-period comet and in this manner developing a habitat, which was literally surrounded on all sides by a great mass of valuable resources, very rich in volatiles. The application of that idea, in this year's paper, is to emphasize that such a habitat could be the second basket into which we could put our terrestrial eggs, preparing ourselves against the inadvertent extinction of terrestrial civilization. I think in some respects he went too far, and in some respects he didn't go far enough, but this is a provocative idea and one that carries promise for the future. The respect in which I feel that he went too far is requiring

long period comets. Many asteroids and short-period comets are also very juicy things, all of which are much more accessible to our planet. The way I think he didn't go far enough is that, statistically speaking, that second habitat would have a shorter expected lifetime than earth itself. Therefore, what you really want to do is have lots of habitats. If there's anyone who objects to that, please don't say anything.

The next paper was given by John Lewis, from the University of Arizona. I've introduced him and criticized his work here in the past. Professor Lewis presented a blizzard of partially digested data, presented at high speed, all of seemingly unrelated facts. But the essence of the paper, as I understood it, if there was a point, is that the concept that asteroids and low-mass resource sites are somehow very restricted in locations in the solar system is an archaic idea. Just about anywhere we look, in orbit around planets or in belts around the Sun, we can find local supplies of resources in bodies small enough so that we can land on them readily and take away their goodies.. Why he took so much time to express that simple sentiment I can't understand.

That brings us to the end of Session 5.

VI. INTERNATIONAL, LEGAL, AND ECONOMIC CONSIDERATIONS

Chair: James Dunstan

I had the honor of chairing the last session, which means I have the honor of giving the last summary, which means that if I do this in less than nine minutes, then we get out at the appointed hour of time.

The session was on International, Legal, and Economic Considerations in space development and manufacturing. I began making some apocryphal comments about how I was injected into this system in 1985 and it became very clear to me that this particular session was of particular importance to Gerry O'Neill. For it doesn't matter how good your engineering is, if you haven't got an economic or a legal construct that allows you to do what you want to do, it's all just gonna be paper studies in the end. So you have to understand the dynamics of the social sciences as well as the hard sciences, to ever have a chance to go forward.

The first paper was presented by William Hulsey, entitled "Extraterrestrial Intellectual Property Right: The Need for a Legal Economic Paradigm." Bill began by preaching to the choir a little bit, talking about how space is, in fact, the next economic frontier for mankind. He then began to talk about both the pitfalls, the hurdles that are in our way, as well as the tools we have to advance the economic growth of outer space, and specifically pointed to a couple of these, such as the 1998 Commercial Space Act, and the fact that we have an operational International Space Station, which is now going to force us to confront some of the intellectual property issues. The

main difficulty is that the world does not have a harmonized intellectual property regime by which we can protect the intellectual property developed in space, and specifically Bill talked a bit about patent issues, and the fact that the United States has a different regime, a first-to-invent regime as opposed to first-file regime, which is much more common world-wide. The problem arises in determining whose laws to apply to inventions created onboard an international space vehicle such as the ISS. Bill's conclusion that we really do need to work on an international organizational front to harmonize patent laws in the same way that we've done with copyright laws, and working toward with trademarks. But we're not quite there with patents yet and, in fact, since patents tend to have the highest value in intellectual property right now, we really need to push that regime forward to harmonize the U.S. approach to patent protection with that in other countries across the world.

The second paper was presented by Ken Malpass, entitled "Profitable Condominium Development Using Self-Replicating O'Neill Colonies." Ken sort of threw onto the table the "miracle of compounding" and the fact that if you "invest" construction resources correctly with a high rate of return (assumed to be a one year doubling rate), one can conceive of replicating the hard assets of space condominiums in a system that rivals O'Neill Colonies in just a few years. Ken made the case that if, in fact, we were able to allocate resources now and invest in such development by building the infrastructure necessary to generate such a replicating system, that in fairly short order full-fledged colonies in space would emerge. Ken believes that if one million people were to dedicate \$2000 per year in an IRA for ten years toward this project, the \$20 billion generated would provide enough seed money for them to construct, and then sell for a profit their small condominiums, which would provide the resources for them to "move up" to larger space-based assets.

I liked his approach in that he sort of threw it on the table, threw the "fish" of the concept on the table and then watch it flop around — inviting the audience to comment. Indeed, Ken's concept engendered significant discussion. Questions were raised as to whether critical mass in terms of economic resources could be generated to get the first few condominiums built. Someone also suggested that this was nothing more than a pyramid scheme, that always required the "greater fool" to buy the lesser condominium to allow for the next stage in replication. The issue was also raised as to the assumptions Ken made about the cost per pound to lift the necessary supplies to orbit, which he assumes to be \$100/lb, or roughly two orders of magnitude lower than current launch costs. Finally, the question was raised as to whether there really are 1,000,000 individuals willing to go to space, especially if it would require them to wait for a certain amount of time until their "ticket was punched" to go.

The next paper was presented by Dr. Amanda Moore, the National Space Society's representative to the UNISPACE III conference held just after the last SSI conference, in July 1999. Amanda's paper was entitled "What Hath UNISPACE III Wrought?" Amanda literally walked us through the conference through the use of maps of the convention center layout and summaries of the

reams of documents produced. One of the major new features from past UNISPACE conferences was the inclusion of nongovernmental entities at the session, and the establishment of the "Space Generation Forum" — designed to allow young professionals the opportunity to participate in developing future space policy.

In terms of the substantive issues raised at UNISPACE, several were important. First, the delegates issued a statement as much as admitting that the Moon Treaty of 1979 and its "common heritage of mankind" language really needs to be rethought. Amanda emphasized that there was a strong undercurrent at UNISPACE III that this is a different world than it was in either 1967 when the Outer Space Treaty was adopted or certainly 1979 when the

Moon Treaty was adopted and then ratified by only a few non-spacefaring countries. Amanda submitted that the international political environment may be ripe to readdress issues of property rights with hopes of adopting an international legal regime that has a little more flexibility in terms of property rights and what we can do in terms of exploiting and using and developing outer space.

Three other issues of substance were debated at UNISPACE III. First was a continued recognition that steps need to be taken to mitigate space debris, because we're all guilty of throwing our junk out into space, and somebody needs to tell us to clean it up. The second was the issue of using nuclear power in space for deep space exploration vehicle. A growing consensus exists that nuclear power sources are necessary for deep space exploration, and the real issue is how to educate the public that such power sources are not intended for low Earth orbit, but are intended to go completely out of the Earth's gravity well. Finally, the UNISPACE III delegates took up the issue of intellectual property rights in space, and began to discuss how we develop a proper intellectual property regime in outer space.

Next up was Paul Fernhout, who presented a paper, "A Review of Licensing and Collaborative Development with Special Attention to Design of Self-Replicating Space Habitat Systems." Paul's background is in software development, and specifically in the "open-source" development community. What Paul looked at was that while we have all these great minds in the space community, there is virtually no collaborative efforts to develop standard building blocks for infrastructure development. We talk to each other one-on-one, two-on-two, but we don't talk mass-on-mass, and we certainly don't collaborate very well as a community to build things or even to conceive of things, to simulate things. Paul compared this to open-source architecture in software, that has produced things like the LINUX operating system, and maybe that is an approach we should take in the space community to define and develop space habitats, large space projects. Paul undertook an interesting analysis of the time value of all the people who are critically interested in space, and who if they devoting a small amount of their time and their talent, the same way the open-source software group works, how much value it would add to developing the building blocks of space habitats.

The other thing about in the open-source software development community is that they have a well-defined licensing scheme for the use of the software, which could be applied to the results of collaborative space designs. With open-source software, you know from the license designation whether you can make commercial use of it, make derivative works based on the open-source development, or whether all subsequent work must remain in the public domain. That's a problem with the current space community, since we don't know every time we grab a chart off somebody's Web site if we've got the rights to use it. Or every time I go use something, has somebody else got a patent on that, which is going to be increasingly important in years to come. Quite frankly, two years from now I may end up having to talk about that if we continue at this rate, in terms of some of these process patents we're seeing.

Next up was Bob Werb, as part of the team of Bob Werb, Rick Tumlinson, and Jim Muncy, the commercialization troika. Bob talked about the International Space Station and their analysis of what is the proper management tool and management regime for an international space station. Bob comes from the earthbound real estate world, the development industry, and I thought it was a very interesting approach, the way he broke down a real estate project into its three components. You have your development and planning team, your construction team, and your management team. And if you have the same group doing all three, you're doing something very, very wrong. Somewhere along the line, the project needs to be handed off, because each one of those activities requires a different skill set. Yet here we now have a real estate development in outer space where the same group planned it, built it, and is now, for the foreseeable future, managing it.

Bob looked at the four main reasons given for it's the ISS's existence: the development of technology and engineering, the advancement of science, the development of commerce in space, and international cooperation. He looked at three possible ways you could manage the ISS if you wanted to maximize those four different items. One is what we're doing right now, and obviously if he agreed with that approach, then this would have been a very short presentation. The second approach was the idea of totally privatizing ISS, just sell it off to the highest bidder, and it doesn't matter if that bid is one dollar or 10 billion dollars. Finally, one could look at the formation of the equivalent of a port authority or a civil authority, some sort of quasi-, not governmental, but a management team that could look after it. Bob and Rick and Jim's conclusion is, in fact, that if you laid out those four goals for a space station and you've looked at those three alternatives, the formation of an International Space Station Authority (ISSA) is the way to go. This is the first step, in fact, the concept of this first manifestation is only a few months old. We will probably be seeing more of this again, and I hope in two years, maybe Bob or Jim or Rick will come back and tell us where they are in developing further this concept.

Which leads to the final presentation of the day which was mine, entitled "Doing Business in Space: This Isn't Your Father's (or Mother's) Space Program Anymore." I talked about my beginnings with this community in 1985. We had the space shuttle that was flying often and we

were told by NASA we were going to have all sorts of wonderful things in commercialization. Then a few months later Challenger went boom and the thoughts of commercialization all went away. In fact, we've sort of been wandering in the desert since then. I looked at the time span between 1999 and 2001, since last we met, and looked at the developments in commercial space. I looked at things like blowing the doors wide open on the idea that you, in fact, can buy and sell property in space. Foundations like FINDS, providing early seed funding for many projects that are critical. The Dreamtime of multi-media deal to commercialize some of the assets of NASA. The Space Act Agreement with Skycorp which allows access and commercialization on space station. All to the good.

But then I talked a little bit about the fact, through a very recent experiment of a RadioShack commercial filmed just last week on the Space Station, as part of a Dennis Tito flight, and I showed the payload, which was a personalized photo album, that went up to both astronaut Jim Voss and Yuri Usachev, the other male member of the crew, and the only problem is, we could only show the Russians, we could only do a deal with the Russians, because NASA prohibits its astronauts from appearing in commercials, or at least in commercials it thinks are too commercial, which is kind of interesting.

To explain why it is relatively easy to do a commercial deal with the Russians, and nearly impossible to do one with NASA, I gave the audience the "Know Your Space Agency" quiz. And you all did a wonderful job and scored exceedingly well on it. But I then posed the question and answered it myself, if we gave that quiz to the average public and asked them who runs a capitalist space program, which runs a socialist space program, they would probably get the answer wrong, because we know that, in fact, contrary to what you would think, that the Russians are capitalists right now and NASA are the socialists. However, sometimes, dramatic climatic change forces instant mutation and evolution and that's my dearest hope for NASA, that they are going to be shocked into a different state of consciousness now that the Russians are really on our heels, because real money for the Russians is forcing them to do some things that NASA wouldn't do on its own. And I promise to be back here in two years, hopefully not without having done quite a few more of these types of deals and in the end analysis, we'll be advancing all commercialization efforts in space.

Applause.

Lewis: I think that was a great note to end this on, don't you? Okay. Thank you all for coming. Come back next time. Bring your friends, your children, your grandchildren, your great-grandchildren, okay? Get the picture? Have a great two years.

Applause.

ROUND TABLE DISCUSSION

Planetary Defense Misconceptions and Opportunities

Moderator: George Friedman

On Monday evening of the conference, a spirited two-hour discussion was held by the following panelists:

Professor Freeman Dyson, SSI President, Institute for Advanced Studies,
Princeton Dr. Lee Valentine, SSI Executive Vice President

Professor George Friedman, SSI Research Director, University of Southern
California Professor John Lewis, SSI Director, University of Arizona

Professor J. Richard Gott, Princeton University

William E. Burrows, New York University and author

Dr. Neil DeGrasse Tyson, Hayden Planetarium

The panelist around a rectangular table and were rounded out by virtually all the conference attendees sitting in the audience.

Misconception # 1: *Since the annual probability of an NEO strike on Earth is very low, there is only an insignificant risk to humanity.*

Lee Valentine started the proceedings by observing that, although the *average* daily probability of a strike on Earth by an asteroid or comet is low, the yearly probability is greater, so that for long periods the probability is 100%. There are still thousands of undiscovered NEOs which will impact Earth with the energy to destroy a city, a country, or even Earth's agriculture --causing millions to billions of human casualties, *at any time, INCLUDING TONIGHT!* There exists no comparable threat to civilization and humanity.

George Friedman was the discussion leader for the remaining misconceptions. The interaction with the audience and the panel was far more intensive than the conference paper presentations and at any given time there were about a dozen hands raised to ask questions or contribute comments. Over an hour into the meeting, Friedman pointed to two raised hands and said, "David..." whereupon both David Kuck and David Criswell spoke up simultaneously. After each spoke, Friedman commented that the likelihood of two Davids being lined up to within an arc second and wishing to speak simultaneously was surely less than 10-10, yet it happened that night! This is not a frivolous example; it illuminates the general confusion between long-term average probabilities and specific events in support of Lee Valentine's earlier remarks.

Misconception #2: *The planetary defense community is the primary beneficiary of NEO search programs.*

Due to the dedicated efforts of a small and idealistic band of planetary astronomers -- aided substantially by advanced focal plane technology and data processing -- the catalog of asteroids larger than 1 km has increased from a few dozen in the 1980's to over 400 today. Thank goodness that there are no Earth approachers in this group. During the next decade it is likely that this number will at least double and very *unlikely* that we will find an earth approacher even in this expanded catalog. (Note, this is no excuse to stop looking; see misconception #1) However, consider the enormous benefit than even these 400 NEA's represent to the space exploitation and colonization community! We have received the gift of over a trillion tons of material, far more diverse than the surfaces of the moon or Mars, and completely outside of planetary or lunar gravity wells.

John Lewis commented: "Among the 1400 NEA's of *all* sizes catalogued so far, about 300 are more accessible from an energy standpoint than the lunar surface."

Assuming that NASA can accomplish its ambitious and unlikely goal of \$500 to lift a pound from earth to orbit, the cost of placing this vast resource into near-earth space would be \$10¹⁸. That's a billion billion dollars, or several millennia of gross *world* product! The trillion tons would provide 150 tons of material for each person in today's population; far more than O'Neill's earlier estimate. (Most of this material would be used for shielding in the habitats, so we need not be too sensitive to its diversity; that is, all the mass of any given asteroid would be useful.)

Misconception #3: *L5 is the place to go to build human space habitats.*

Gerry O'Neill's original and brilliant vision was to build space habitats at the earth's Lagrange points employing material delivered from the lunar surface by mass drivers. In the second edition of *The High Frontier*, he began to reconsider this architecture and acknowledged the increasing importance of NEA's. As was described by Friedman in *High Frontier III* (ref 1) page 166, a lunar based mass driver powered by square kilometers of solar collectors would take decades to deliver the mass to space habitats at L5. As was stated several times in this conference, "Go to where the mass already exists in near earth space and exploit it for over 99% of the mass requirements of the space habitats." This will save decades of time and probably tens of billions of dollars. Consulting the planetesimal population model in Gehrels (ref 2), page 300, reveals that there are 100,000 NEA's, each of which can supply almost all the material for an Island One habitat supporting 10,000 folks. Or, if you don't prefer small town life, there are 7,000 NEA's, each of which can supply the material for small cities of over 350,000 population. The orbits of these NEA's lie mostly between 1 AU and 2 AU from the Sun and it would be a feasible engineering challenge to provide a year-round Hawaiian-type climate for these space faring pioneers.

Misconception #4: *As we apply mass drivers to the deflection of Potentially Hazardous Objects (PHO's), we should strive to attain higher velocities of the ejecta. After all, the common wisdom for chemical rocket design is to maximize the exhaust velocity of the combustion products, isn't it?*

As Melosh (ref 2, p. 1117) accurately points out, in applying mass drivers to NEO deflection we should strive to *minimize* ejecta velocity and maximize the ejecta mass, commensurate with the available power. With all the investment in providing the energy, whether it be solar, chemical, nuclear, etc, one would like to believe that most of it can be converted to the kinetic energy of the PHO, thereby avoiding an earth impact. Unfortunately, a complete analysis which considers both the conservation of energy *and* momentum reveals that just the opposite is true by a very large margin for most circumstances. The amount of energy which couples to the NEA is only $1/(k+1)$ of the available energy, where k is the ratio of ejecta delta velocity to NEA delta velocity. With reasonable advance warning of a year or so, the NEA need only develop a velocity of a fraction of a meter per second, whereas the mass driver which is designed to deliver pellets of mass out of the lunar gravity well must develop thousands of meters per second.

Thus, mass drivers designed towards their original purpose have a k of several thousand and if used for PHO deflection would couple orders of magnitude more energy to the ejecta than the threatening asteroid. On the bright side, Melosh (ref 2, page 1119) shows that, if a few years of advance warning were available, NEA's as large as 1 km could be deflected by a mass driver with an ejecta velocity of 300 meters/sec powered by a solar collector of 100 meters radius.

Misconception #5: *In deflecting PHO's, we must be concerned with their rotation. This was a major factor in A. C. Clarke's, "Hammer of God" and in several other papers of the intercept community.*

A straightforward analysis reveals that the ratio of an NEA 's translational kinetic energy to its rotational energy equals $(5/2)(V_t/V_s)^2$ where V_t is the translation velocity we wish to impart to the NEA and V_s is the surface velocity of the asteroid relative to its center of mass. According to Harris (ref 3), most asteroids rotate only a few revolutions per day. Thus for most deflection circumstances, NEA translational kinetic energy is thousands of times greater than rotational kinetic energy. The most effective strategy then would be to zero out the asteroid's rotation at the earliest opportunity rather than let the deflection efforts be crippled by attempting to carefully synchronize the deflection forces to small time intervals of the asteroids rotation cycle.

Misconception #6: *Within the planetary defense world; the detection and intercept folks have great respect and admiration for one another and have proposed a balanced systems plan.*

Considering the absolutely outstanding interdisciplinary work performed by astronomers, geologists, paleontologists and atmospheric physicists in defining the NEO threat and bringing it to public attention, it is regrettable that the systems engineering and management aspects have

been so neglected. Generally, the detection and intercept communities have acted more like competitors than comrades. They have failed to agree on even the most fundamental requirements issue: the size of the NEO to be considered as the basic target for detection and intercept. The detection community says "1 km and up", citing the "peak of risk" and the greater difficulty of searching for smaller NEOs, while the intercept community argues for "100s of meters and up", citing the tens of millions of casualties worthy of saving and the greater difficulty of intercepting the larger objects. In the conduct of the two workshops that NASA conducted in the early 1990s, the detection camp severely criticized the intercept folks for examining technologies which would not be available until substantial development was accomplished. Moreover, they were very critical of the early drafts of the AIAA position paper to the US Congress (ref 4), advocating a better balance of effort between detection and intercept. Even within the detection community itself, the Spaceguard Survey (ref 5) recommended only terrestrial telescopic search, despite the potential of other valuable methods such as long range radar to provide range and range rate to augment the telescopes' angle and angle rate data, and the employment of space-based sensors.

On the bright side, a recent paper by Clark Chapman (ref . 6) who was one of those most critical of the intercept workshop and the AIAA position paper, states, "At the present time, the impact hazard is often treated -- if treated at all -- in a haphazard and unbalanced way." He goes on to advocate a more balanced "systems approach." Also, the United Kingdom completed a study in 2000 which advocated a balanced approach between detection and intercept efforts.

Misconception #7: *When 90% of the NEO cataloging will be accomplished, 90% of the risk will be mitigated.*

This would be true only if intercept could be accomplished in time, once an incoming threat is identified. If the time is too short, the detection would be worthless in reducing risk, and indeed would actually lengthen and perhaps intensify the world-wide panic. The situation could be likened to a chess player who only concentrates on the next move, without adequately examining the dangers of accepting his opponent's queen sacrifice. Admittedly, a warning about impending tsunamis due to small NEOs would provide more time for the evacuation of seacoast populations, but the detection folks are concentrating on the much larger NEOs. This leads us into:

Misconception #8: *The detection and intercept folks are demonstrating mutual respect by employing these two "reasonable" working hypotheses: Detection folks: There will be enough time to intercept a PHO once we see it's coming our way. Intercept folks: We will be given a reliable probability of hit before we commit to an intercept.*

Both these hypotheses are dangerous illusions. Presently, the emphasis on working -- or even *thinking* -- about intercept is virtually zero, probably due to the vocal arguments from the

detection camp that the very scarce resources are best employed to get the PHO catalog up to at least 90% and that "several decades" of warning will be provided. In contrast to this view, Don Yeomans and Paul Chodas write (ref 7), "It is interesting to note that approximately one third of all NEOs are discovered near their closest approach to Earth that they will experience in the next 200 years." The warning time for the asteroid 1989FC was a negative several days for that near miss. These opposing views to the illusion should insert some rational uncertainty into postponing *all* intercept work. An effective intercept system would be as complex as any weapon developed in the history of military research and development and should include all the phases of requirements definition, preliminary design, testing, manufacturing and deployment; not to mention the additional time-consuming needs for rendezvous with the PRO, transporting the intercept mechanisms to the PRO and the long process of actual deflection. Far easier systems than the NEO interceptor have taken three decades or more to develop. If insufficient time would be available, then we would have to resort to a nuclear design, which everyone claims is to be avoided.

The situation is further aggravated by the hypothesis that the probability of hit will be available. Yeomans and Chodas (ref 8) describe the difficulty of predicting orbits several decades in advance. For example P/Finlay, which is predicted to approach to 0.047 AU of the Earth in 2060, has a predicted 3 sigma position uncertainty of over 400,000km! This is over an order of magnitude greater than "target earth". Our present state of astrometry doesn't permit a reliable probability of hit until we are much closer and have used up most of the precious time- to-go. The value of radar measurements to provide range and range rate data augmenting the telescopes' angle and angle rate data was eloquently described in the 1992 Spaceguard report (ref 5) but was ignored in the summary and funding requests. The improvement of astrometry by radar has actually suffered budget cuts in recent years (ref 10) and noted astronomers have argued against space-based discovery missions with NEO detection as the mission (ref 11).

Misconception #9: *As we perform deflection missions, it is only necessary to move the NEO by an earth's radius. That should convert a hit into a miss.*

Friedman (ref 9) has shown that even if the uncertainty were as small as the target itself, and we chose to move the NEO laterally by one or two earth diameters decades in advance, the likelihood that we would convert *what would have been a miss into a hit* is as high as one chance out of six. Clearly, if we wish to avoid moving the PHO by *tens of earth radii*, we will need *far superior* precision, decades in advance.

Freeman Dyson: "The advantages of long warning times are so great that it would be worthwhile to invest in greater accuracy of orbit determination and more rapid orbital computational convergence."

Neil Tyson: "However, today's state of the art of accurate orbit determination is rather embarrassing. (Displaying a copy of the Mar 12, 1998 issue of the New York Post, with the headline: *Kiss your asteroid good-bye.*) "One day they predict an impact of the asteroid 1997XF 11 in 2028, and the very next day -after incorporating additional data from JPL, they retract the prediction."

Misconception #10: *Movies such as Deep Impact, Armageddon, and the earlier NBC special, Asteroid, serve to constructively heighten public interest in the importance of planetary defense.*

The technical inaccuracies in these science fiction "blockbusters" are very disturbing. Compared to the movie 2001, there appeared to be little thought or concern about the realities of technology and science. Worse, they employed the ancient sci-fi paradigm that all that was required to save the day was heroism and on-the-fly technical pyrotechnics rather than patient foresight and strategy. (Hailing back to Buck Rogers' Dr Heur, Flash Gordon's Dr Zarkov and Captain James Kirk's Mr. Spock.) Entertainment was the game, with not even the smallest message that we should think well in advance to develop search programs or the necessary technologies. Our supporters in Congress are very concerned about the "giggle factor" of anything that has its origins in science fiction and are averse to the appearance that they are taken in by immature technological schemes.

Lee Valentine: "In the last few March Storms, I have not observed any reduction in the support of our Congressional supporters of planetary defense. In fact, staffers this year had a better idea of the asteroid threat."

William Burrows: "Recently, my son and I noticed a truck driver delivering a load of mattresses while listening to rock music. He was obviously happy in his own limited world. If he viewed these movies, they could have opened his mind to new concepts of space and its dangers. An asteroid would no longer just be an abstract rock 'out there'."

Neil Tyson: "Education normally progresses in small, digestible steps. These movies, as terrible as they were technically, served to introduce to the masses concepts of hazards from space that they never even dreamed of. So: lighten up, George and accept them as something you can't change anymore and something that probably has had more benefit than harm."

George Friedman: "I sincerely hope you're right. Nonetheless, it's too bad that the spoofs by *Mad Magazine* on these movies have provided better science than the \$ 100M epics themselves!"

J. Richard Gott: "On a much broader scale, humanity has had a much shorter history than the average species of mammals and it's uncertain whether we can maintain our concentration on this problem for the many generations necessary to save ourselves from extinction. It's difficult for our culture to look past our lifetimes into hazards and mitigation strategies that stretch well beyond our lifetimes."

Jane Valentine: "Humanity *is* a very special species that has survived all the extinction pressures that have caused the demise of other mammals --except the NEO hazard. We owe it to our children -- over many generations -- to take reasonable steps to mitigate this remaining hazard.

After two hours, the formal meeting ended. Several churning knots of smaller discussions formed immediately, excitedly continuing debates on the issues, with gesticulation punctuated allegations, contentions, pontifications and exhortations. ..on into the night. ...

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