SUMMARY OF THE CONFERENCE SESSIONS

I. ASTEROIDS AND NONTERRESTRIAL MATERIALS

Chair: John S. Lewis
Summary: John S. Lewis

I shall begin by pulling Dave Kuck's two papers together and treat to them as a unit. His first paper, "The Deimos Water Company," should be recognizable by all of you as an application of an idea he has been working on for many years, that of building a mechanical anopheles mosquito to suck the lifeblood out of some poor, innocent and unsuspecting asteroid. This has inspired a device which has actually appeared in a science fiction vignette in "Mining the Sky," a device called the kucker, which the attendees at this conference would have no difficulty recognizing.

Dave's fundamental point, and fundamental motivation is that water is a universal solvent for getting around the Solar System: it solves the problem of transportation. It also solves the problem of life support. It is tempting to paraphrase the mistakenly quoted Willie Sutton who, when asked why he robbed banks, supposedly said, "because that's where the money is." Dave has asked the question where's the water? He has rather daringly taken on Deimos, which has a reflection spectrum that looks carbonaceous, except for the absence of the water band at three micrometers. But I think he is justified in doing it. It must suffice for me to say that we know that the surface materials in Phobos and Deimos have been shock-heated, recycled, ejected from their surfaces and recaptured repeatedly over the history of the Solar System. We have every reason to believe that the surface material should be anhydrous. However, we also strongly suspect that the bulk material was carbonaceous because of its very low reflectivity across the visible, and because of the extremely lower bulk densities that were determined for both Phobos and Deimos by measuring their sizes and their gravitational fields. We must ask ourselves, when we find actual undisturbed Solar System material with that high a carbon content and with that low a density, what is it made of? The answer is: it contains twenty percent water. It's called carbonaceous chondrites type I, or, for those with long memories, type one. They're the same thing.

Dave's second paper on "Decision Points," emphasized that a necessary precondition to exploitative missions to asteroids is an improved knowledge of their composition. One does not want to send out shotgun exploitation missions to asteroids whose properties and value remain undemonstrated. Therefore there is an extremely high prior value placed upon achieving spectral characterization of these asteroids. We can do quite a remarkable job from Earth for all except the smallest of the near-Earth asteroids. Conventionally the spectral range covered is about 0.3 to 1.2 micrometers, because it gives the widest spectral slice you can get through the largest single optical window in the Earth's atmosphere, and provides very useful diagnostic information about the presence of many important minerals. Ideally, we need to get out beyond the visible, in the 0.9 micro region, you get the diagnostic information about what the major silicates are. That's what tells you about the abundance of iron-bearing olivine and pyroxene, which are by any account two of the five essential ingredients of Solar System solids.

Dave points out that, beyond that minimal characterization, you may be frequently driven to cover more of the UV and the infrared. I have to agree with that, but I also point out that there is still one possible stage intermediate between Earth-based spectral characterization and an exploitation mission, which is a micro spacecraft visit. Such visits become more and more affordable all the time: we even have a number of examples in the list of presently planned missions. You have heard ways in which we can do it. Jim Benson wants to capitalize on existing technology and get started in the business of sending small spacecraft to characterize economically interesting Near-Earth Asteroids up close. Of course, such spacecraft would be sent to asteroids that have already been spectrally characterized from Earth.

Intrinsically, these small spacecraft are not enormously expensive. They can be run off a production line. Missions to, say, fifteen different spectral types of near-Earth asteroids would actually involve almost identical instrumentation in every case. There is no reason we can't clone that payload. If only we could self-replicate that payload, that would be wonderful, but we need to wait a while for that! But we can get started now. I certainly hope that the Benson endeavor will fly in the near future.

The second paper of the session was that by Jeff Kargel, and since Jeff was unable to come, I gave you an 'off the top of the head' preview of the contents in that session. I see no point in repeating a summary of my summary here.

The third paper was by Chad Hicks and Kumar Ramohalli. Kumar and I are the co-directors of the Space Engineering Research Center at the University of Arizona, and Chad is a graduate student in the Aerospace Engineering Department there. Chad told us a two-pronged story. One was a pure gadget story, and the other was an application story. The gadget side was a reminder of the astonishing devices called muscle wires. In making mechanical systems to operate in alien environments, having lots of moving parts is often a great hazard, a source of potential failures. In fact, my biggest problem with the helium 3 retrieval story is the mechanical complexity of the processing equipment, which I see as a nightmare of possible breakdowns. I shouldn't say possible breakdowns: certain but unanticipatable breakdowns. Muscle wires are nice because they give you mechanical motion with a device, which, like a muscle, does not move, it simply contracts. Properly packaged, these mechanical muscles would be enormously useful for powering all kinds of motions. Chad talked about several applications. You can do everything up to and including driving wheels. The real beauty of it as I see it is that they minimize the number of moving parts. There are still some unresolved problems having to do with how fast you can cool the wires, and how to design systems to have the rapidest possible cooling. If you have a thick wire and heat it, it contracts and it takes a long time to cool. At this early stage of their research they haven't really addressed that yet. Nonetheless, it is rather obvious that if you cool the wires quickly, you can execute quick motions. If you want simple, rugged, and reliable robots, keep in mind that these wires can go through hundreds of thousands or millions of cycles without apparent degradation. There's a great deal to be done with them.

The next paper was by Steve Gillett, "Implications of Molecular Nanotechnology for Space Resources." He has exposed a piece of a multi-headed iceberg. Part of it is Biotech, starting with living organisms and engineering them to do some useful tricks. Part of it is truly molecular nanotech, which I find to be a truly exciting long-term prospect. It is long-term in a very interesting way: many long-term prospects ramp up a little bit at a time. This is one that may come upon us almost unawares, very abruptly. We'll go from having virtually no capabilities to it being a dominant technology in a very short period of time. I don't know why the world is spending so little money on these ideas, but let me tell you that we need to see this technology pushed and driven and applied. I don't recall whether Steve made this point explicably or not, but, the mineralogy of most of the raw materials in the Solar System is rather simple. There are only about five major minerals that you need to deal with. Iron nickel, iron sulfide, olivine, plagioclase feldspar, and pyroxene. The degree of complexity necessary to take those five apart isn't necessarily daunting. It's not as if you needed to have an excellent refinery, like one of Bob Waldron's processing plants on the Moon that has one hundred and forty three processors and three hundred different products — you don't need to start like that. So, let's get on with this, but let's not stop doing what we're doing now while we wait for it. Let's push this along and be prepared opportunistically to inject this into the stream when it becomes ready. Then you will see an enormous leveraging of our capabilities. I'd also like to remind you of what George Friedman said in his summary, about the general potential of nanotech. It will be an interesting challenge to devise ways to power these devices so that they can extract metals from oxides.

The last paper of the session was by Ken Stapleford on "Possible Uses of Surface Tension to Shape Space Structures." Here's another idea that's crying for an experiment. It's a simple, straightforward notion: use the vapor pressure of one material to inflate large spheres of another fluid, then freezing or coating that resulting larger sphere to make an enclosed habitat. His discussion of habitats was not part of my session, and most of the critical remarks that I might make would apply to his application; therefore I will not make them. Nonetheless, a small space experiment along these lines, should be relatively easy to design. The experiment must be designed to that it's not terribly sensitive to gravity gradients, which may be difficult to do very close to Earth on a large scale. Therefore we should think in terms of a small experiment. Perhaps then we can find a way to make large spheres. I am a profound believer in the importance of inflatable space structures. You've all heard evidence in previous conferences about their potential. You also know they are anathema to NASA. I find that to be a second outstanding recommendation for the idea.

This ends my summary. I apologize for making it so short, but as you understand time is at a premium right now.

II. TRANSPORTATION AND SPACE STRUCTURES

Chair: Leik Myrabo
Summary: Lee Valentine.

When Gerry O'Neill was at these conferences, he was always pleased to note increasing relative numbers of experimental papers versus theoretical ones. So I'm very happy to say that in this session we had two papers that summarized experimental results.

The first paper I'd like to talk about is by Derek Tidman, "Slingatron Mass Launch into Space." This is, I think, quite a neat idea. It is a mechanical analog, of the synchrotron. Of course those of you who were here two years ago know this already. Slings require low continuous power, guns require high, pulsed-power. As you can see the sling has a distinct advantage in its lower peak requirement. Here is a picture of the table-top slingatron with a 1 meter diameter hoop. This model accelerated ball-bearings to 100 meters/ second. Here is a curved section of the I beam proposed accelerator ring. The advantage is that this machine can be made out of the sorts of steel that currently exist. They can be polished to mirrored surfaces and can be welded together using standard techniques.

This, of course, is important with that sled riding around on the wall. This is steel on steel. So how do we mitigate the frictional forces? Well, gas bearings look like they answer that problem.

Here's a diagram of the sled. High pressured gas comes out the bottom of the vehicle; the tube is, of course, evacuated. The radius is upward. As this gas comes out, it levitates the vehicle on a thin gas bearing. It does eventually leak an atmosphere into the hoop but that apparently is not a show stopper. And here's a final artist's conception of the proposed slingatron. The important feature of this artist's sketch is that you can tap out the projectile at any point along the exit spiral, and so eject it into any number of different orbits.

Here's a final simplification of this slingatron device which was first presented here at the Space Studies Institute Princeton Conference two years ago.

This is a mass accelerator. It appears to be capable of accelerating quite large masses, and accelerating smaller masses to quite extreme velocities. So it is an interesting and exciting concept. It's obviously more mature now than it was in 1995. We look forward to seeing more about it.

The next paper was "Universal Crew Vehicle," and here we see one of an excellent Russian design. It's been in use now for nearly thirty years. I guess that's true, thirty years. Chris Faranetta proposed that we enlist some of this excellent Russian expertise to produce a crew return vehicle, an updated model of the trusty old Soyuz.

The next paper was "Stabilization of the External Tank for Use as a Large Space Platform." We're very well aware of potential uses for external tanks. Of course we didn't carefully address the dynamics of moving these things around and how they should be stabilized for on-orbit utilization. Wes Kelly has proposed a number of damping mechanisms and looked carefully at the dynamics of what would have to be done to actually use these things. (Next view graph please.) There's a nice separation sequence, gives you an idea of what happens and when, it's a Shuttle mission profile. This is the kind of mission profile that we'd like to see the Shuttle fly.

The next paper was "Kinetic Energy Supported Electrically Powered Transportation Structures" by James Cline. One of the great things about this conference is we always have some imaginative ideas that make you think. This is a kinetic analog of the space elevator. It has a couple of interesting features, but it is a device that appears to be more suited for a Universe with different physical or economic laws.

The next paper, "Design of Micro-Gravity Spherical Space Habitat," I think is the closest analog we have of this was a brief passage in an Arthur Clark novel written about forty years ago, or nearly forty years ago called "Voyage by Earth Light" in which he describes a micro-gravity space habitat. A large globe of water with a bubble of air in the center serves as a swimming pool and cafe. The cafe is, of course, inside the bubble of water that's centered in the sphere. John Lewis referred to some engineering problems with the design of a very large, thin-walled, pressurized micro-gravity spherical space habitat, that forbid the sort of structure proposed here.

The next paper was titled "Implementation of Space Radiation Shield for Subsonic Maneuvering Propulsion Following Re-entry." This sounds like a characteristic Leik Myrabo title because his papers are always very imaginative, every possible parameter is pushed as far as it can possibly be pushed. But unfortunately, Leik did not present this paper. He presented a paper which might be better titled "Report of the First Flight of Sub-scale Laser Launcher or Lightcraft" with that I would like to show you Leik's video with the audio, this time.

Leik is an old friend of ours, he presented what I would call a very imaginative paper here about 18 years ago. In this paper, his spacecraft becomes smaller and more rugged, and the power supplies have become more dense. And now he has experimental results. So I think he is making progress.

(Commentary during video presentation: These are heavy models, they need to lose some weight. Now the intense blue you see is the plasma discharge. The laser pulse frequency is ten hertz and so it sounds like a machine gun.)

So the summary of the positive points in this session was the table-top demonstration of the slingatron concept, the flight test of the laser powered launch vehicles, and further exploration of actual dynamics of maneuvering large structures in space. Of course, I have a wish list for 1999. Firstly, I would like Chris Faranetta to ask our Russian friends, if we'd could to see a nice tri-propellant chemical rocket engine. It's not laser propulsion, but it sure would make it a lot easier to build single stage to orbit rockets.

Then I'd like to see a restart of mass-driver work This is something we'll have to assess with George Friedman. I'd like to see a report of constructing something on the Moon or on asteroids. How do we affix structures to asteroids to move them around? Rather than seeing enormous space colonies, I'd like to an economical design for a minimal space colony. Something for 10 or 20, but no more than 50 people. Something that's large enough so that you don't get cabin fever, yet small enough not to make the shielding mass prohibitive. I'd like to see some more on reflectors and solar sails. And of course we're looking forward to having a successful first test flights of the X33.

III. INTERNATIONAL LEGAL AND ECONOMIC CONSIDERATIONS

Chair: James E. Dunstan
Summary: James E. Dunstan

Day two of the Conference began with Session Three, the Legal, International and Economic Aspects of Space Development. At the lunch in the middle of the session, Vladimir defined a pessimist as a well educated optimist, to which I, as the token lawyer of this group, responded, no actually a pessimist is merely an optimist who has hired a lawyer. And sometimes this session, historically, has supported that comment. Everyone is very optimistic after the technical presentations, and then the lawyers and the economists come in and say there is no money, or there is someone who is going to sue you if you do what you want in space. Fortunately, I don't think we have quite as many negative aspects going on in the nine papers that were presented. But nonetheless there were some cautionary notes raised.

The first paper was entitled: "The Space Settlement Campaign: A Tool for Social Acceptance and Support for the Space Settlement Concept" given by Steve Wolfe, a former policy wonk and congressional staffer on the Hill. Steve looked at the space advocacy movement, and asked: What has it done? What should it do? and Where do we go from here? Steve pointed to a couple of successes that the movement has had. One was the help in passage of the 1988 Space

Settlement Act and the impact on President Bush's speech which set forth the Space Exploration Initiative. That's the good news. The bad news is those two things listed above had zero consequence on space policy or progress on the High Frontier. NASA has never provided the reports required under the Space Settlement Act to Congress. And of course we all know what happened to the Space Exploration Initiative of President Bush.

So, getting stuff done in Washington isn't enough. And Steve asked, why isn't that enough? Frankly, it is because there is no deep or broad public support for space, according to Steve. We have a community that has failed to convey the goals of space settlement to the public. And those of us who were present for Steve's presentation, still hear ringing in our ears from the terms, 'Tang and Teflon is not enough,' which became a mantra by the time he got done with it, saying it about seventeen or eighteen times. What's his solution for this? He sets forth a broad platform, what he calls the Space Settlement Campaign. It begins with writing down a declaration, understanding what we are all about. And for this group, it's no stretch, because we know what those concepts are. George Friedman eluded to it earlier today: we are the choir, we know the tune, but the key is to write down what we believe.

Second, the Space Settlement Campaign challenges us to take what we believe and turn it into public expression. He used the analogy of the Million Man March, of Minister Louis Farrakhan. You may not have agreed with anything that was said there, but you couldn't ignore it, because so many people were involved with it, and it was so well orchestrated as a PR event. He suggests, probably not the Million Man March, but a Million Robot March might be a good beginning. To start from New York, for some reason, probably because he lives there and he thinks that nobody thinks of New York as the hot bed of Space Advocacy, down to Washington DC. Something to energize the public, and get some interest going. The third part of this campaign is to develop and distribute relevant materials using the technologies that we have today, the Internet and the media. The fourth is to develop educational tools. To hook them when they're young. To get the next generation interested in space. And finally, to support the legislative agenda that includes cheap access to space and commercial access to the Space Station. And so Steve challenges all to become involved to the extent that we can.

The second paper was given by Wes Kelly, who had previously given a paper in another session. It was entitled "Observations on the Infrastructure and Space Commercialization Problem". Wes began by defining a problem which we are pretty well aware of, and that is if we continue on our present course in the civil space program, you will see no more than 50-60 civil servants in space in a given year, and even that may be optimistic. That's not acceptable to anyone in this room, and that's not acceptable to Wes. He looked at some analogs for developing technology such as air races between World War I and World War II, indicating that progress in air development was really fueled by the private sector and these sorts of competitive initiatives, not by a government program. He suggests the same thing could happen in space. This is not anything new to this group certainly. But his main point is that we should focus on the actual assets we have in our inventory right now, and not technologies that are over the horizon and as yet untested— things like the Delta II and the Atlas II vehicle. Use and modify them, as opposed to, or in addition to, the more radical concepts that this group is more familiar with in terms of new transportation methods.

He made us look at what has happened in the past, the inventory assets we have thrown away. We all know the about the loss of the Saturn V, and cry about that every year. The industrial space facility, that was never developed or properly utilized. And the reasons they weren't, were not technological reasons, they were political reasons. How do we jump start this? What he proposes is that we need to get NASA to step back with long missions, and specifically he suggests that we should require that a resupply space station be done on a contract basis and therefore allow private companies to continue building and utilizing the assets we have, the launch assets in inventory and make them better, on an incremental and evolutionary basis. That way we get from fifty or sixty civil servants to a much more robust space economy that this group has called for since its inception.

The third paper was entitled: "International Cooperative Decision-Making for Space Exploration into the 21st Century" presented by Eliger Sadeh. He is a Ph.D. candidate at Colorado State University. What he is attempting to do in his Ph.D. studies, is to look at the dynamics of international cooperation in space activities, and his presentation was an early glimpse of that work. At the outset, he challenged this group by saying: "I'm going to say something that a lot of you aren't going to agree with....NASA counts." That's not something that all of us would necessarily agree with every day of the week. Eliger's point was that we must look to international cooperation if we hope to undertake large scale space projects in the future. He went on to posit that the best way to reach your goals is to understand the political dynamics of international cooperation. And so what he wants to do is to look at some case studies of international space missions and try to understand the dynamics of the process, and then use that as a predictive model for the future. He identified three major dynamics of any international cooperation by looking at where the power resides -- who are the dominant players, who are the less dominant players? Where do the varying interests and preferences lie? Where does the knowledge lie? Where does the knowledge transfer lie? By looking at these questions, he has developed four models that he thinks can explain various cooperative space efforts. One he calls the Structural Model, in which one powerful nation calls the shots, and everyone else falls in line. The second is the Convergence interest and compromise or converge them into a mission. Third is the Institutional Model, and that would be where individual nations agree to establish some organization above themselves to undertake a particular mission or oversee one aspect of space development. Finally, he has what he calls the Epistemic Model which is characterized by a grass-roots emphasis. He then went on to look at a couple of case studies that unfortunately he was not really able to get into in detail because of time constraints. He looked at the Apollo-Soyuz Test Mission, the development of ESA as an institutional model and of course going forward with the International Space Station. There were questions raised afterwards of whether or not you could use this as a predictive model, but his hope is to look back at some case studies and help us as a country and as a space-faring civilization. Eliger's point is that when we look at undertaking a mission we should have an idea of what we're getting into when we sit around the table and say, "yeah let's go jointly to Mars" or something like that. We look forward to seeing more of Eliger's work as his Ph.D. studies continue.

The fourth paper presented was "The Potential Role of a Space Development Bank Accelerating the Commercial Development of Space," by Dr. Tom Matula. Tom is an Associate Professor of Marketing at the College of West Virginia. Tom's premise was that we've got space entrepreneurs on one side, we've got commercial potential of space that we all have heard about on the other, but we have a financial barrier between them. No surprise to this group at all. What he is proposing is that when we look at analogous situations, we find that space development is not much different then third world development, and there have been actions taken to allow third world countries to develop themselves, by the establishment of things like the World Bank.

The same sorts of problems that plague third world development also impede growth on the High Frontier: high start-up costs and high-risk. But similar to developing a country, there are some high payback potentials. So he proposed to establish essentially a Space World Bank, except that it would be a United States Government entity which would be funded to the tune of between five and ten billion dollars. It would use the government's ability to borrow at approximately 5-6 percent, and then would loan money out to entities wishing to develop space. Tom argues that with a 4 or 5 point spread between the amount such entities borrowed and the rate at which they paid it back, you could, in fact, fund this mechanism and cover your bad debt. In addition, the Space Development Bank would serve some of the same functions as the World Bank. In terms of education, it would provide some educational workshops, bringing together space types like us, and giving us a little better education as to the way the real world, the economic world, works. And he said exact projects that this might be applicable to would be solar power satellites, spaceports, industrial facilities, tech transfer, and commercial RLV's, ELV's. The Space Development Bank would be a direct lending, start-up loan refinancing entity, and act as a financial intermediary to other capital markets. This is one of the things that the World Bank does fairly well, to provide the seed capital, mature the venture into a bankable risk, and then introduce the venture to more established money players who can provide the follow on financing. Again, The Space Development Bank would provide research policy and support mini-courses and seminars. Tom believes that this model can break the financial barriers down with just a few success stories, which could result in substantially more traditional dollars being vectored into space development activities.

The next paper was authored by Paul Roseman, entitled "Economic Retrieval of Space Debris." Paul took a look at a specific problem from an economic standpoint. Paul sought to conceive of a single particular activity that could be done in space that would provide a payback. Paul decided to analyze the retrieval and use of debris in orbit. He began with the assumptions that you have a start-up cost of 10 million dollars, and a retrieval satellite weighing two thousand pounds, boosted into orbit at $5,000 a pound. Thus, you have twenty million dollars in capital investment, but you don't have the World Bank that we just saw, you need to go out and you need to get venture capital, and give them their typical twenty percent rate of return. You give yourself a small office, which is nice, and you'll have to have some on-orbit maintenance costs. All together he believes it is going to cost you about a half million dollars a month to run this business. If you look at where that money is going, it's paying back the loan which is financing this venture.

Balanced against the cost side, if we can assume that we can get two hundred dollars a pound for some of the stuff that's hanging up there, and if we can manage to bring back two thousand pounds a month to our orbital maintenance facility, you would gross six hundred thousand dollars a month. At that point, you are above break even, and making a little bit of money off the venture. During the question and answer there were some issues raised, such as what do you do with all the stuff once you get it to LEO? Does a "yard sale" model work, whereby you assume that there will be a buyer for every piece of space junk recovered? Some suggested that you just wouldn't have a huge amount of players that will buy anything if you put it out on your front lawn and put up a sign. Nonetheless, this is an intriguing approach to look at, and one of the good suggestions is that Paul should think about coming back two years from now and look at another component - the economic benefit of eliminating space debris which might provide a substantial additional market for Paul's proposed retrieval activities. It was suggested that if Paul could factor that into his equations somehow, either through a tax on ventures putting things into space, or a bounty on bringing junk back down, the revenue numbers could increase substantially, and offset the initial cost that people have hypothesized that you would incur to be able to actually remanufacture the space junk when you get it down into LEO.

The next presentation was, entitled "Towards a Code of Conduct for the Exercise of Intellectual Property Rights (IPR) in Space Activities — Moderation of the Monopoly?" and was originally going to be presented by Brad Smith who was unable to be with us. I stepped into the role, and so as John Lewis said earlier, you are now going to hear a summary of my summary of his paper.

Brad took a look at the real problem of patents in space. On the one hand you have the Outer Space Treaty and its language we all know. Exploration and use of outer space should be carried out for the benefit and interest of all countries irrespective of their degree of economic or scientific development. Space shall be the province of all mankind. All right, that's your international law on the one hand. Let's flip over to the U.S. Constitution on the other. We are one of the few countries in the world where protection of intellectual property is actually in our constitution, appearing early on in Article One. It's not far down from "We the people..." quite frankly. And that provision states: "Congress shall have the power to promote progress of science and the usefulness of arts by securing for a limited time to authors and inventors, exclusive rights of their respective writings and discoveries." So you've got it! It's broad, it's for everybody. The United States from its outset is telling the world that we will protect the rights of inventors.

Now here's where it gets really interesting. For the International Space Station, there is an agreement concerning intellectual property that is convoluted and doesn't make a whole lot of sense. It's not very clear who gets what patent rights where. With apologies to Brad, I jokingly said that there are going to have to be very large signs on the bulkheads between the various countries' modules, which essentially say "Leave all your ineligible property behind, you are entering foreign soil." But that is, in fact, what the Intergovernmental Agreement is trying to do by basically saying; "whosoever module you are in when you discover something, that country's laws that apply."

Additionally, there is the problem of preemptive patents — patents that if upheld, would foreclose completely some aspect of space development. Brad's paper talked about a recent TRW patent in which they patented a process for providing communication signals from any orbit between five thousand and ten thousand miles to any handheld unit. Now that's a pretty broad patent. In fact, anybody looking at that would say, that pretty much precludes all LEO and MEO communication satellites because TRW has a patent. What has happened in that case was, the various two thousand ton guerrillas all got together and said 'let's agree not to fight for the moment.' So the Bill Gates' and the Motorola's and TRW have all gotten together and agreed that TRW is not going to enforce its patent rights.

Brad's paper uses this example to conclude that a code of conduct for space patents is necessary so that we don't run into the TRW patent problem on a regular basis. He is proposing that all countries must recognize certain things that we simply should not patent in space because to do so would completely obliterate our ability to use it in the future. And he would point to that TRW patent as an example of something that from an international basis we should agree we cannot allow to be covered by patent. On the flip side though, he is saying that we must strengthen the rest of the world's approach to patent law, because we have to give incentive to people to develop products in space.

The next paper was delivered by Bob DeBiase: "SETI Telescope Relationship to Lunar Infrastructure and Implications on Keeping Far-Side Radio Interference Free." Bob began with a chart which outlines the radio bands where SETI searchers believe they have the best chance of receiving alien radio signals. The problem is that they are junked up all over the place on the Earth, because we use the same bands for everything from TV to cellular telephones. So if we are interested in SETI, then we really ought to look at trying to find interference free zones in the near Solar System, and it turns out that the best possible place is the far side of the Moon. Bob then went on to look at a whole set of possible ways of delivering a SETI receiving infrastructure to the far side of the Moon, and looked at it from the standpoint of a tradeoff study between cost and reusability of the infrastructure for other exploration and development. Bob concludes that, probably, there is never going to be enough money to do far side SETI radio-astronomy just for the sake of doing that. But if we can reuse some of the components for other uses, we may have a chance of getting a SETI operation up and going. Bob looked at several different models, beginning with landing two tethered interferometer telescopes. If you can manage the landing of two separate simultaneous observatories without breaking your cable, you've got a relatively cheap solution. The problem is, that's all you get for your mission - there would be no infrastructure re-use.

A second scenario is a set of inflatable satellites that actually hang around in L2 on the far side of the Moon. You get a little bit of infrastructure re-use, but not a huge amount. The third would be a far-side deployment of a telescope with a lunar-orbiting satellite. Here you know you get some more infrastructure reuse, because near-side lunar activities could make use of the satellite as it travels overhead for intra-lunar communications. Bob's third scenario is a more elaborate phased-array radio telescope on the far side. Again he would use that orbital satellite, a rover, and then a solar power generating station. The idea there is that you probably spin off more solar power than you use for your SETI activities, which you could sell to other far-side users. Finally in the far corner of Bob's master chart, is a scenario where the SETI deployment becomes the backbone for a vibrant far-side lunar base, where all of the SETI infrastructure can be reused by other parts of the lunar economy. The problem here is that you've got a lot of mass that has to get to the far side of the Moon.

In conclusion, Bob understands that there are high transportation costs, but that the idea is to try to team with other people wanting to conduct activities on the Moon, and how to best optimize the SETI base size to fit in with these other uses. Finally, Bob cautioned us that everyone needs to talk about frequency use on the Moon, to make sure we don't junk up the Moon the same way we've junked up Earth from the SETI people's standpoint.

Larry Roberts gave us a paper called "Environmental Regulation of Solar System Resources," and this probably could be characterized as the most traditional international space-law report to this conference. Larry began by looking at space environmental regulation from an international treaty standpoint, then working his way to customary international law and U.S. domestic approaches to such issues. In this regard, Larry's presentation tracked the approach taken by Brad Smith in the area of patents. Larry focused on how we can deal with the environmental consequences of being in space from an international law standpoint. The problem being is that we have very, very loose terms defined in the Outer Space Treaty and in domestic law as well when it comes to environmental issues, and there is this overarching idea that there are not really any property rights in space as the Outer Space Treaty has been interpreted. The problem becomes, therefore, that if there are no property rights in space, then there can be no accountability for environmental damage caused by entities in space. Larry therefore argues that the international space community needs to invest entities with property rights in order to give people something to fight about and to defend and give them responsibility and accountability for their space activities. Larry's approach may be a little bit different from very traditional space law interpretations, but it was a very interesting approach that raises a fundamental issue of whether there can be accountability for space activities without the benefit of some sort of property rights regime.

I gave the last paper in the sequence titled "Earth to Space: I Can't Hear You; Selling Off Our Future to the Highest Bidder." I looked at some things that are happening as we speak that are very disturbing to me as a communications attorney and as a space lawyer. We have witnessed two policy shifts of interest. One is that a significant amount of radio frequency spectrum is being taken from government use and put into private use. That in and of itself is actually a good thing, given the fact that the private sector has become much more efficient in its use of the spectrum than have government users. There is a second policy shift, however, that when combined with the first is extremely disconcerting. That is the fact that the Federal Communications Commission is auctioning off \spectrum to the highest bidder, which unfortunately has caused the "law of unintended consequences" to grow exponentially.

Recently 200 MHz of spectrum has been taken away from the government and given to the private sector. Of interest to this community are services such as radio-astronomy, and NASA's Deep-Space Network which is losing spectrum to private use. The assumption of most people was that, as that spectrum was shifted over to the private sector, it would be used for similar purposes. So it didn't really bother me that a piece of the Deep-Space Network might be shifted to the private sector, if in fact I could use that spectrum for space-based communications as a private sector individual interested in space activities.

Unfortunately, the second policy shift is what really has caused the problem, and that is the conclusion from the FCC that it is going to auction everything off to the highest bidder, regardless of the use proposed for the spectrum. To add some perspective, let's look at the numbers involved. The personal communication service (PCS) located in the 1.8 GHz band, generated 23 billion dollars in auction proceeds. Compare that with a civil space economy where we're talking about a potential cap on NASA funding somewhere in the 10 billion dollar range by the end of the century. Moreover, the Clinton budget assumes there is going to be an additional 23 billion dollars in auction revenues from additional spectrum poured into the federal coffers. With that mandate, the FCC is now shifting its entire allocation mentality, saying, rather than looking at how we allocate spectrum on its best use, it will look instead at how much money can be earned from auctioning off the spectrum. A recent example bears this out. The FCC has created a new communications system called Wireless Communications Systems. No power limits, no use restrictions. And by the way, some of the frequency they grabbed included launch range and safety frequencies. So any private launch companies out there, you better hope that nobody orders a pizza 60 seconds into your flight or it may get blown up. Or as John Lewis pointed out, more likely you are not going to be able to punch the button in case your rocket is starting to head back into a populated area.

What am I suggesting? We, as a community, must activate on this issue. We must make ourselves heard. I hate acronyms, so I use really bad ones on purpose, and have chosen the Ad Hoc Space Communications User Group or SCUG, as the name of a group that needs to be formed to become active in this area, to say "Hey, if you're going to take frequencies from the private to the public, make sure you still retain their use as space frequencies, because there are technical reasons to do that." Individually and as a group we need to do that, and then we should get involved with groups like Space Frontier Foundation, and NSS on a legislative agenda that argues that auctioning off frequencies in space is a really bad idea because once the US government does it, every other country in the world is going to do it. So you're going to have to pay the piper on every orbit. What will be the result if we don't come together to fight this issue? Then the future of space communications may be no better than two tin cans and a string, because that's all that space ventures will be able to afford when competing with a next generation cellular telephone system. That concludes my review of Session 3. Thank you.

IV. WIRELESS POWER TRANSMISSION

Chair: Seth Potter and Peter Glaser
Summary: Seth Potter

I am happy to see a lot of new faces in the Wireless Power Transmission Session. If you were not here for Friday's session, I want to once again convey Peter Glaser's apology. He was originally supposed to chair this session, but he and Buzz Aldrin were called to Washington to testify before Congress, so I think that was a good opportunity for them to promote some things that we are all interested in.

Since we're pressed for time, I want to take this opportunity, to put the papers in this session into an historical context. Some of what I am calling history hasn't happened yet, which is even better, because we hope it does. And so, one thing we had in common is: we all put our work in the context of the 1970s reference solar power satellite, which was five by ten kilometers in geostationary orbit, supplying five gigawatts of power and weighing tens of thousands of metric tons. This requires a large infrastructure in low and/or high-Earth orbits and possibly on the Moon as well. We all spoke about some of the more recent trends toward lightweight inflatable structures, such as the Spartan inflatable antenna. Although the Spartan experiment was not specifically designed as an SPS demonstrator, some of the smaller designs that have been considered are only a couple of times bigger than this, so if it can work for an antenna, we hope an SPS is not going to be too far behind. Another thing that we all had in common is that we hoped that the increasing use of cheap access to space, to use a phrase that is very popular, will make SPS cost-competitive with other forms of energy in the near future. So there are certain things we all agreed on. We all put our work in a certain past context, that is, we were trying to improve upon the size, mass and large first costs of the 1970s version of the SPS. And we were all trying to take advantage of what we see up here; some future opportunities which we hope will come to pass.

The first paper was by Bill Brown who spoke about "The Early History of Wireless, Power Transmission." Here is a photo of Bill Brown demonstrating wireless power transmission in this very room two years ago. This is Bill's schematic of a wireless power transmission system, and you can see that basically DC from anywhere, for instance solar energy, can be converted to microwave energy, and beamed into space, or beamed across space, or any distance you want, since it is not attenuated across free space, to any significant degree. There it is collected and converted back into DC power by an array of antennae known as rectifying antennae or rectennae, and then you can do with it as you please, just as you would with any other source of power.

Bill then showed us an actual apparatus he used at Raytheon to test this concept. There you see on the left side of the screen, a feedhorn, beaming a couple meters across the room to a rectenna array. Now, let's go back to the other graph for a second to make a point, that overall, the efficiency of this sort of equipment is very high. The history of efficiency improvement you can see here; Bill, of course, gave us the total context of the history of wireless power transmission, and wireless technology in general, which started with Maxwell and Hertz, who, you could say, in some sense invented radio. We don't really see much in the way of efficiency in the late 19th and early 20th century. It was enough that the idea simply existed. And when Bill started working on the concept beginning in earnest in the 1960s, you can see that the efficiency rapidly went up and that 54% is, I believe, a point-to-point total efficiency. Not too bad, considering in principal we will get this over distances from Earth to geostationary orbit. Of course, we haven't tested it as such yet, but since conventional power transmission is limited to a few hundred kilometers because of resistive losses, wireless energy transmission in general seems to be a very promising technology.

The next paper was by Richard Duncan who spoke about "The World Petroleum Life-Cycle: Encircling the Production Peak." He spoke about what he called Numerate Empiric Model, and compared it with the model of M. King Hubbert, a geologist who tried to predict the future availability of petroleum. What Richard's work does is to combine numerical analysis with empirical observations about how world politics and policy function. And he concluded a number of things; for instance, in the early 21st century, oil production would peak and then start to decline and not long after that, OPEC would dominate world petroleum production. And what I found interesting, is that what he was attempting to improve upon, Mr. Hubbert's model, basically handles the classic bell-shaped curve, in which production of any resource starts slowly, then increases exponentially, reaches a peak as the resource is exploited, and then starts to taper off as the resource is depleted. What Richard's model does, is that it takes into account all the kinks and twists of current and possible future political factors. Now what I found interesting about this paper is that it is important for another historical reason. If you read Peter Glaser's 1968 paper in Science magazine, you will see that he was actually led to the idea of the solar power satellite by looking at world fossil fuel production over the course of civilization, mainly over the course of the past six thousand years of civilization, and the next six thousand. If you graph world fossil fuel production on an axis that has a scale of several thousand years, you'll see that it occupies a relatively brief time. So that's what led Peter to this idea in the first place. So I found it interesting that Richard is looking at petroleum production curves, but looking at a much more narrow window of time with much greater detail. But the idea of doing so certainly has historic precedence.

Now let's jump from history into the future a little bit. The next paper was by John Mankins from NASA Headquarters. He outlined NASA's recent 'Fresh Look Space Solar Power' study. He gave a little bit of history from the government point of view, in which after the 1970's SPS study, the Office of Technology Assessment, said that research and development should continue and that the question of deployment should be revisited in ten years. However, nothing happened for fifteen years. John's office began looking at the idea again in light of some of this new technology in 1995. So it's only recently that NASA has begun reexamining this idea. They examined a couple of dozen different types of systems architectures, and evaluated them in terms of cost, risk, feasibility and so on, and came up with about 6 or 7 most likely candidates.

Among them were geostationary solar disks, which can beam power to two different locations at once, and there were some other concepts involving global power grids. The concept that seemed to be most promising was what he called the Sun Tower which could be in LEO (low-Earth orbit) or perhaps more favorably in MEO (middle-Earth orbit). The Sun Tower is a large stalk-like structure, with disk-shaped concentrators, focusing solar energy onto small photo voltaic cells. There would be a number of these going up and down the central shaft. This would be an inflatable self-deploying structure. The large variety of systems architectures that he showed reminded me of Peter Glaser's statement that if you ask what's the best way to build a solar power satellite, he would say that's like asking what's the best way to build an airplane. So John showed us a number of feasible types of systems architectures and described how they might fit into the possible space infrastructure by supplying power.

The next paper was by Eric Flint, who talked about the use of solar power satellites to supply power for emergencies and disasters. His basic concept is that if you take a sub-array of a transmitter from a solar power satellite, you can direct the beam to more than one location at the same time. Of course, this leads to lower power densities, which in Eric's case is not a problem, but an opportunity. What you are doing, is if you have some sort of natural disaster where the power infrastructure has been knocked out, what you want to do is flood the area with power. You don't need to worry about the long-term effects over twenty years of being exposed to this;

you just need power over a course of days, weeks, or just hours to rescue people. And what is interesting to note is that Eric considered perhaps as many as five beams going in different directions at once, and he limited the amount of energy to a peak of five milliwatts per square centimeter, which so happens is the US standard for microwave oven door leakage. So if it became necessary to flood the area with power, and erect portable rectennae, you are not going to get any more exposure than if you stood next to a microwave oven and watched a potato cook for awhile. What he was aiming at was dual-use technology; that it really doesn't pay to build a solar power satellite just for this purpose, but if you have such a system anyway, it would not be too difficult to divert the beam on a temporary basis for emergency use.

Of course, he spoke about some other uses: disaster relief, refugee camps and so on, and active control of buildings in case of earthquakes. Damping systems for skyscrapers in case of earthquakes have been widely considered. One bottleneck of this technology is the fact that in an earthquake you are likely to lose power, so active damping tends to be a bit problematic, but Eric said not necessarily so: if a power line snaps, and if the building or area near it is equipped with a rectenna, there is an alternative. Of course, we are talking about very wide beam footprints. The power may be rather dilute, and it still takes up quite a bit of land area. Possibly even more land area than a traditional beam if you are going to use a sub-array of the main transmitter. However, Eric thought that in some situations this could be an opportunity. If you have an airplane down or a ship in trouble and they have an emergency rectenna, even if you are not exactly sure where they are, you could just flood the area with power, and they would likely be somewhere within that multi-kilometer footprint. So Eric considered what was basically a series of problems: the beam was wide on the one hand, the beam was dilute on the other hand. But it may not necessarily pay to build an SPS system just for disaster relief. And in a sense, to use John Lewis's phrase "marry the two" functions of an SPS.

Now the last paper of the day on Friday was mine, in which I discussed five major issues that would affect SPS deployment. Some of these are things that others have considered before, such as cost of access to space and low-mass inflatables. What I'm holding is an actual piece of thin-film solar cell. The environmental costs of fossil fuel burning may push the costs of conventional energy up even as low-mass inflatables and cheap access to space push the cost of SPS power down, so the two may be equal sooner then we think if the world decides it wants to, for instance, tax carbon emissions.

I should add that this was an invited book chapter by Marty Hoffert and myself for Peter Glaser's new book on solar power satellites. We, like John Mankins, have considered the developing nations as a possible new market. We can model a low-Earth orbit system of SPS's in the fashion of some of the proposed communications networks. This viewgraph shows the Teledesic system of Bill Gates and Craig McCaw. John Lewis talked about marrying Earth and space, so I like to think of this as the wedding ring. You can link the entire world with a power grid, the same way you would with communications, thereby levelizing the cost of electricity. In fact, the power beam could actually be the communications beam if you modulate it. By adding demodulators to the rectenna, you could communicate over the same beam that you transmit power with. This would be ideal for those areas in which some entrepreneurs have proposed supplying communications to, but which currently have no electricity. Well, now it may be possible to do both at the same time.

Now to wrap it up, I would say that at the last SSI conference, I was also privileged to give the summary session of the Wireless Power Transmission Session, and I said at the time that I was looking forward to 1997. I'm certainly quite pleased with what I saw, and I'm looking forward to 1999, with one caveat. I'll go back to the photo of Bill Brown and his demonstration in this room two years ago. You can see that the power is beaming from here, bouncing off this mesh and up to this microwave powered helicopter. So you see, power being beamed up. I would like to see the power go the other way, and start tapping into that zero-mass resource from space, high energy photons, which can be sent down and converted at high efficiencies. So again, I'm looking forward to 1999, and we'll see what happens then.

V. BIOMEDICAL CONSIDERATIONS

Chair: Richard Satava
Summary: Logan Smith

There were four papers given in the Biomedical session this time. They were all excellent papers which addressed issues vital to long-term residence in space. The first paper was by William Stone, about increasing redundancy and safety in personal life support systems. I think anyone who wants to be a dweller in space or traveler in space would applaud that increase in redundancy. He has worked with scuba gear and analyzed the safety, redundancy and the fail active modes of the scuba gear. Whether one is say four hours away from your base, exploring an underwater cave or four hours away from your base repairing a satellite, building a solar power satellite, or on the face of the Moon or an asteroid, you don't want to have a situation occur that if one part of the system goes out the entire system fails. I think I would applaud that if I were the one four hours away. What they have done in their underwater gear is to have two separate systems, either of which can take over from the other. Two separate oxygen systems, two separate carbon dioxide scrubber systems and they actually have a fail-safe position in which they could fall back on and do manually if both of those systems fail. Once again, I think it is a good plan and one that is a little bit better than what NASA has on a space suit. So that was a good practical paper.

The second paper was by Andrew Newberg and Abass Alvi and given by Dr. Newberg. The paper, "The Study of the Effects of Long Duration Space Flight on the Central Nervous System Using Modern Imaging Techniques," was a little bit more of a theoretical paper. They explained the techniques for using CT, MRI and then the new toy on the block, the P.E.T. scan, to study what happens to the central nervous system after long term exposure to micro-gravity, radiation, and all the other nasty things in the orbital or space environment. It was an intriguing paper for myself as a physician, and perhaps it was a little more difficult to understand for those not used to looking at MRI's and CAT scans. MRI is an excellent anatomical tool for examining things. We use it serially, say for brain tumors, for solid body tumors now. Positron Emission Tomography is where you use a metabolic tracer element combined with different metabolic substrates such as tagging glucose or tagging dopamine molecules to show dopamine receptor activity in the brain. This is one of those technologies that is in search of a mission right now. The PET scan has been around for about ten years and makes beautiful color pictures of brain activity and glucose uptake by the brain, where you can say, "ah ah, here's the fellow solving the mathematical problem. You can see that the left side of the brain is potentially working." The only problem is, from my experience and from one report that I've read, some people with innate mathematical ability—that is people who are good at solving problems—don't get any increase in metabolic activity while they're solving the problem. It's only people who do not do well in solving problems, and suddenly they have to take up their entire brain to solve two plus two equals four, that showing an increase in metabolic activity. So PET is still a wonderful technology in search of a mission, but it does make very pretty color pictures. But not to be glib, it was a very good theoretical paper, and it is a model for the kind of basic research that we will have to do when we become dwellers in space just to see what the long-term effects are.

The next paper was presented by Janine Abarbanel from Colorado State University entitled "Inflatable Structures for Moon/Mars Surface." If we are going to be "planetary chauvinists," we will need something to live in. This is not a crib, it is an inflatable structure made of kevlar. They have done extensive work over the last couple of years determining the self-deploying inflatable structure that gives the most usable interior volume for the least amount of material and what they have said you can do is make each one of these things to be put on a twenty by twenty floor area, 400 square feet and you can link them together to form colonies which are self-deploying. Then take your bulldozer and cover them with lunar regolith which reduces the stress that they'd have to take and that's a lot lighter weight than carrying aluminum structures or trying to make your own foam-regolith or compressed-regolith structures on the Moon or on Mars. And then she had a nice picture that illustrated what it would be like to be inside one of them. I think there were some concerns about abrasion and electrostatic stuff with the dust on the Moon and with people going in and out, but that's valid in any type of lunar structure.

The next paper was given by Dr. Satava who gave us slides and view graphs. This seems to be a continuation of a talk that Shawn Jones gave in 1995 when I ended up chairing the discussion of the summary session once before. What they are talking about is essentially having a physician using telepresence to do surgery and diagnosis on the fore-edge of the battlefield. This may or may not come to be, as far as telepresence surgery is concerned. I'm sure that they will make it work successfully on certain types of laparoscopic surgery. But their vision includes a whole scene where you have MASH trucks running out and about on the battlefields picking up wounded soldiers, sticking probes in while someone back a hundred miles away operates on them. As a surgeon that could be drafted during a war, I think very highly of it myself, rather than running around dodging bullets and mortar shells at the forward edge of battle. What the implications of this are, whether it comes about in medicine, is a refining, a proving of the technologies for telepresence and teleoperations for anything we want to do in space. And I applaud that, because the precision you're going to use to do surgery is orders of magnitude higher than most anything other than fine machine work having to do it with telepresence operations on the Moon, or at an O'Neill colony or wherever. Actually, even with the fine machine work, this surgery is much more difficult because you are usually receiving something that doesn't move or squish out of the way while you're trying to operate on it or move it. Once again, this illustration shows how it works. Soldiers moving this little coffin-looking thing, then loading it on an M-113 track vehicle which has linkage through to the surgeon, me, sitting way back here in a nice tent somewhere across the Persian Gulf. But once again whether this comes about as far as medicine goes, I think it is a valuable tool for our needs, for anything we're going to be working on in space. I applaud DARPA for the work they've been doing and we're all grateful for their assistance and long-term support.

VI. ROBOTICS

Chair: Lalitesh Katragadda and Red Whittaker
Summary: Lalitesh Katragadda

In his Keynote, Red Whittaker of Carnegie Mellon spoke of wide ranging robots from automatic harvesting, to assisted surgery with the common thread of robots involved in human enterprise and being integrated in the mainstream of global commerce. He spoke of the inevitable migration of robots into space, preparing and providing for human arrival and survival. Over fifty robots from all over the world were profiled along with distinctions that would contribute to realizing the dream of robots in space, operating in remote and hostile environments for extended periods.

Sojourner and the future of Robots on Mars: (http://mpfwww.jpl.nasa.gov) Donna Shirley, head of the NASA Mars exploration office spoke of a rover already in flight, the Sojourner micro-rover on the Mars Pathfinder Mission. It's a shoe-box sized rover which is landing on Mars on July 4th. Its main purpose is to demonstrate robotic technology, exploring Martian rock fields for the first time; photographing, touching and sniffing them.

The Sojourner mission leverages ten years of technology in locomotion and robot demonstrations of light-striping based safeguarding and on-board intelligence. It has a sub-calculator intelligence of one hundred thousand instructions per second. More interesting missions are planned in the future with reduced landed mass, enhanced intelligence and capability. The, landing mass at this point is about two hundred and fifty kilograms, including a ten kilogram rover. In the future, this will reduce to under one hundred kilograms and increase the capacity of the robots to over a kilometer rather than the tens of meters for the pathfinder mission.

A sample return mission will happen in 2005 which needs to land with extra precision. Where the challenge to land on Mars (with more than 9 min. communication delay) and then servoing to a beacon, requires brand new landing technology. In the current scenario, the Pathfinder executes an aero breaking maneuver, deploys parachutes, fires thrusters and finally inflates huge airbags, bouncing five or ten stories high, and rolling around before stopping. But this is going to be more complex in the future when the landing needs to be more precise. A future innovation of this program which is of significance to space robotics and space in general is the ability to land and self-refuel. This presents the possibility of humans to Mars by making such missions cheaper by a factor of two to three.

Ranger orbital servicing flight experiment: (http://www.ssl.umd.edu/homepage/Projects/ranger.html) The next presentation was from Joe Parrish, Program Manager of the Ranger flight experiment. The Space Systems Laboratory at the University of Maryland is building a four-armed machine, Ranger, to fly on the Shuttle and demonstrate technologies for servicing the International Space Station and satellites in orbit. The main purpose is to demonstrate three or four primary servicing operations, leading to a significant reduction of EVA (Extra Vehicular Activity) operation hours. This demonstration will project dramatic cost reduction and gives a commercial reason for robots to be on the Space Station and in orbit.

The flight experiment will be conducted in the Shuttle bay, operated from two places; from the Shuttle, by astronauts who are inside the Shuttle command module, and also from Earth using a satellite relay. The reason for two points of command is to evaluate and determine if we can do as well from Earth as from the Shuttle, freeing up astronauts to do other, more vital operations. Ranger has two arms, and a tether arm which allows motion of the robot base, positioning it for the task appropriately. The two arms will facilitate orbital replacement and servicing experiments. Ranger will also attempt tasks which are not conventionally designed for robotic assembly or disassembly, as an example, one similar to that which astronauts performed on the Hubble Space Telescope, replacing an electronics package. An interesting aspect of Ranger is a camera arm, called the video arm, which can be positioned to give an exact view needed by teleoperators. One of the harder parts of teleoperation is getting the right view and perspective to the operator. The human brain happens to be the most effective device we have right now for making judgments, perceiving the world and formulating tasks. The video arm gives it (the brain) the best possible information maximizing the success of the operation.

Ranger is in the final approval process as a NASA risk mitigation experiment for the Space Station. Scheduling of the launch is underway. Ranger will be verified with a neutral buoyancy vehicle which matches the exact flight configuration and dynamics of the flight article. This terrestrial analog is placed in a water tank to give it the neutral buoyancy that closely simulates the dynamic behavior in space, allowing experiments to verify the design before they build the spacecraft and fly.

Robots to assist EVA astronauts: The next paper was by Donald McMonagle, an ex-astronaut who is now in charge of EVA operations and EVA technologies. One of the strategic moves NASA made recently is to take EVA under one wing and gave it strategic turf to enable extended human presence in space. Donald went through the whole EVA process and evaluated the tasks in front of him and came to a conclusion, that, given the budgets EVA has and given task, NASA cannot do it without robots. And one of the comments made was, "We know we want robots, but we do not know what robots can do." The challenge in front of the community is to create a set of robotic assistants which will have the skill and virtual presence of a human novice where the operators are not necessarily the astronauts, but could be people on Earth, acting as assistants to the astronauts. A good analogy is that the EVA astronaut is a highly skilled and highly paid surgeon, and the robots are the ubiquitous surgical assistants. They might be there when the comes in. A key advantage is dramatic cost reduction of qualifying robotic tools for human interaction. Hence, if we can get robots out of the (Astronaut's) way, or physically restrain them, we can reduce those qualification costs. Then there is a need for reliability and graceful degradation, where failures are not catastrophic. The big issue for large-scale operations on the Space Station or on the planets is logistics. Like wars, a space operation can be won or lost by technology and logistics. It becomes important to have common modules for power, communication, end effectors and hardware, where they might be common among robotic components and also common with the astronaut equipment or equipment in the Space Station itself. This minimizes part count reducing costs, lowering complexity and enhancing system survivability. Most space hardware today is not designed for the kinds of motions of grasping devices, as for example a motor doing hundreds of millions of cycles. Lubrication and tribology become very important issues in space in addition to mechanical and electronic survival. The other criteria EVA robots need to meet is maintainability, (the ability to fix the machine or change parts), repairing or reconfiguring for different operations.

The operational focus is to supplement humans as you would an unskilled assistant. The goal is for robotic assistants with the operational capability of untrained humans, although not as skilled as astronauts, would be very valuable due to an order of magnitude lower cost and an order of magnitude longer space walk capability. Additional cost multipliers are the robots weight requirements, saving two to three orders of magnitude overall (factor of 100 to 1000). This is especially true where the task is repetitive or involves large forces in very risky environments. One example of a risky environment is on a planet. One scenario would have a refueling sortie - sending a spacecraft to refuel itself, while preparing for the astronauts. We do not want to send astronauts with it because if the sortie fails to refuel, the astronauts cannot return. The suggestion is to place robots at the refueling station, where the robots assist with the refueling process and once the refueling process is done, astronauts can safely arrive knowing that they have a way to get back. The underlying objective is to extend the human dimension where we necessarily aren't limited by our physical constraints.

Nomad, public exploration through telepresence: (http://www.ri.cmu.edu/atacama-trek) John Murphy presented a terrestrial analog of a high performance lunar mission which is being worked on at Carnegie Mellon right now. The objective here is a forty day trek in the remote Atacama desert of Chile. This experiment starts on June 18th and lasts until the end of July. The purpose is to demonstrate technology and involve the public in exploration of planetary surfaces and get them into space exploration. It will show that robotic technology is to the point where the public can operate robots effectively, enabled by robots that have gotten that much smarter. An analogy is computers; anyone can sit down at a computer these days and use it immediately, while it used to be that to get that level of operation several years ago required extensive training. The technology demonstrated on Nomad (the robot), which is the size of a small Volkswagen Beetle, includes a transformer chassis which is designed to fit in a payload bay area of a launch vehicle, and the transformer's chassis' property is that the mechanism that opens up the steering is also the steering mechanism, which reduces the number of actuators and also reduces failure modes. Other technology safeguards the machine during teleoperation, using pairs of stereo cameras to perceive the terrain and figure out what is safe, what is not safe and then filter the novice driver commands, ignoring unsafe commands while continuing progress towards a user defined goal.

Nomad will conduct a technological demonstration of the skyline positioning system which adds to a positioning system that already has a GPS and a compass. It has the capability to look at the skyline, use a global topological map to derive simulated skylines and match the skyline against these simulations. The resulting position and orientation is within a hundred meters, similar to the accuracy of a star tracker.

A key component of Nomad is the high bandwidth (~1 Mb/s) communication enabled by a pointed antenna in line of sight to a base station. This elaboration is needed due to the bottleneck of power that all mobile robots have.

The enabling feature of this robot is telepresence imagery from a panospheric camera that uses an upside down spherical mirror looking down on a camera, enabling this camera to happen is the high density CCD (1,000 to 1,000 pixels) and the computing power behind it. The camera uses 400 Mips, compressing the images by a factor of 60-100 and transmitting them stateside over the high bandwidth link.

In late June and all of July, visitors to the Carnegie Science Center will watch the imagery coming back live in an immersive (220 degree wrap around theater) and possibly be able to drive the robot in the control station situated right there. The promised objective is 200 km driving from United States. This is a taste of what would be possible if we did a planetary mission. And one of the results will be a gauge of the human factor; how interested do people become in an immersive exploration experience.

Auditory feedback can revolutionize teleoperation: The next paper was by Seth Potter, Martin Hoffert and D.P. Karron. The primary premise of this paper is that auditory feedback has peculiar qualities that complement visual feedback. The primary tasks enabled by auditory feedback (which are not possible with visual feedback) include warnings (gongs, beeps) from the teleoperation device, and enabling precise positioning (for example a surgical tool) of remote devices with tonal feedback. The other interesting use of auditory feedback is to reduce operator disorientation experienced when seeing rotating images. This hypothesis when demonstrated will have tremendous implications to the effectiveness of telepresence and virtual reality.

In addition to the theory, a current experiment establishes ground truth for remote surgical tools and guides teleoperated surgical tools using auditory feedback indicating the remote surgical tool's location in three dimensions. This, of course, has implications for space including space surgery, where there is the possibility of a nerve center for such operations in one of the LI or L5 points with interesting implications because of time delay transmission, not withstanding time delay that you would get additionally if you went around the Earth land lines or satellites.

Conclusion and Future: Stepping back from these presentations, we have two robots underway to flight, in addition to the Aercam, which is a flying camera launching sometime in the next year from Johnson. This increases the number of robots we have in space from zero to three, which is significant for the robotics community, as it was unproven that robotics technology could fly and be relevant. We also have in the works terrestrial demonstrations and fresh new ideas which continue to energize that process.

The interest beyond technology itself are events outside the robotics community, like the launch market, where the predicted launch market (by Merrill Lynch) by 2002 is about thirty billion dollars. That not only strains the launch vehicle capability, but it also provides interesting problems like orbit allocation of 1500 satellites; placing ITU and other scheduling agencies in a quandary, asking how to get slots for all these satellites and still leave room for the future. One idea is to give satellites autonomous real time collision avoidance capability, and this problem could go away as this will allow high densities of satellites in orbit, increase safety, allow orbital servicing and despin at end of life, reducing space debris. More new technology is required in this arena, for example to take away some of the communication congestion by moving into the optical range using high bandwidth, optical pointing with robotics devices enabling point to point communication satellites; it also enables telepresence through robotics on planets.

Other events that could shape the future of robotics this year are the possibility of ice on the Moon and (ex)life on Mars, those two events have energized NASA to an extent that its falling budget has started to rise. The implications, however, to commercial or enterprise of human endeavor are staggering considering that the energy cost of launching from the Moon is one twentieth of what it takes to launch from Earth. And the possibility of useful materials for refueling and human habitation on the Moon could reduce cost and accelerate space enterprise, providing immediate access to the visions of space mining and manufacturing. The possibility of life on Mars is pushing NASA to investigate, calling for extensive exploration initiatives.

Stepping back to a twenty-year time scale, robotics faces questions like how good are robots compared to humans? Using Hans Moravec's analysis of the computing power of a thousand dollar computer and its upward trend, today we have the computing power of a spider on our desks, and somewhere around 2020 a thousand dollar computer will surpass the computing power of the human brain.

This observation is a little misleading because it does not include the ability we have for sensing. Another comparison shows that the brain has more processing power and more memory capacity than the national telephone network. This points to how we have the judgment and abilities we do. We not only have the information capacity we also posses massive sensing capacity to absorb relevant information that we care about. Each human learns to specialize to his or her environment and work. Such observations give us direction and focus for roboticist's intentions over the next fifteen or twenty years. Robots will get smarter, more capable, reliable and along the way shrink in size. To conclude this projection, adding an order of magnitude to the raw processing power of the brain lets us include all the sensing, computing and memory a human being has.

Somewhere around the 2025, by which time we happen to expect ultra cheap access to space (less than $1000 per kg), we will reach the realm where we can imagine robots with human like capability that are common place in space. These robots will service orbiting space habitats, farm the asteroids and the Moon for materials, build self-sustaining infrastructures, and produce power for terrestrial use; applications that would enable commercially valuable human presence in space, and offload the resource and environmental pressure on Earth. In the last two years, the vision of robots mainstream in commercial enterprise has been seeded into reality. It's not an ‘if’ anymore. And the same is inevitable for space. In this millennium and beyond, we'll see that vision turn to fruition.

ROUND TABLE

Chair: George Friedman
Summary: George Friedman

In SSI's tradition of democratic participation by all its members, a round table discussion on revisiting our mission, goals and other challenges was held at Princeton University on the evening of May 8, 1997. The meeting was attended by virtually all the attendees of the 1997 Space Manufacturing Conference, the discussion was spirited and a full audiotaped record was kept. The observations and conclusions of the round table are summarized below.

The primary issue involved the reaffirmation of Professor O'Neill's High Frontier vision. Despite the fascination that mankind has had with Mars for centuries, augmented by the works of Percival Lowell, H.G. Wells, Orson Welles, Ray Bradbury and Robert Zubrin; and recently intensified by the discovery of possible ancient life on Mars, all attendees to the round table meeting overwhelmingly agreed that the most rational path for mankind's colonization of space was not the surface of moons or planets but the utilization of space habitats far from gravity wells. Furthermore, once the initial developments were established, most of the material and energy requirements for future activities would be derived from the vast resources available in space and that any required physiological sense of gravity could be obtained through rotating structures, not gravitational fields. Many diverse observations were made in support of this decision; they included:

Presently, NASA's budget for new missions to Mars is orders of magnitude greater than the exploration of asteroids; these budgets should be brought into better balance.

Zubrin's recent advocacy in favor of a new frontier for humanity and use of space resources should be applauded, but his focus on Mars at the expense of the asteroids is short-sighted. At the most, Mars could sustain a tenth of the human population, whereas the material contained in the Near-Earth Asteroids (NEAs) could sustain over ten human populations and the material in the main asteroid belt could sustain over a million human populations. Another criticism of Zubrin's approach is that — despite the fact that he is quite critical of NASA management —his plan is just another "NASA stunt" like Apollo which cost over $28B and served to bring home some rocks, leave a flag and some footprints, but establish no infrastructure for future space developments.

Although Mars should not be considered as a primary target for colonization it should not be ignored either. As an object of science, it offers an excellent opportunity to study the evolution of the solar system and the possibility that life originated and existed off the Earth. Bill Schopf (UCLA's Center for the Study of Evolution and the Origin of Life) is not convinced that the tiny objects within the ALH84001 rock are actually a remnant of life, but feels it is imperative that we determine the question decisively by Mars sample return missions.

Lou Friedman (The Planetary Society) strongly feels that Mars deserves the attention it is presently receiving because it has captured the public's attention far more than the asteroids have and will serve to increase the political support for all space programs. He agrees he is speaking from the scientific and exploration point of view (the focus of the Planetary Society) and not the exploitation and colonization point of view (SSI's focus).

The back-row remark, "Mars is a red herring," (rather than the red planet) drew the biggest laugh of the evening.

In addition to reaffirming the High Frontier, many other issues were vigorously discussed. These included:

Scientists in general, and space enthusiasts in particular, tend to be disorganized, politically naive and fractionated into too many diverse groups. Just as we are witnessing major consolidations in our industry, perhaps we should search for more cooperative activities with organizations which have similar goals. Some examples of possible collaborations include those with the Space Frontier Foundation, ProSpace, the National Space Society, the Planetary Society and the Institute of Telerobotics for Space Development. About a third of the round table attendees indicated they were members of the Planetary Society and none felt a "conflict of interest." It was noted that, as we look to lessons learned in the biological world, there are myriads of examples of inter-species cooperation, or symbiosis. Many are consensual, such as the mitochondria in our cells; other are less consensual, such as our enjoying a steak. Most of the attendees agreed that we could carefully develop consensual symbiosis with other groups.

History provides many success stories of new enterprises being initiated by government investment and eventually transferring to the more vigorous, entrepreneurial commercial sector. Western hemisphere exploration by European governments, and the investments by the United States in agriculture, commercial aviation and space communications are notable examples. However, many cases were discussed, including SSI's own Geostar, in which the government stifled commercial ventures by continuing its role beyond what the entrepreneurs felt was proper. Mny round table participants strongly felt that, until a business-like, profit incentivized environment is established, space development would continue to be crippled by government bureaucracy. Where investments in space appear to be merely drains on budgets which many feel should be better devoted to feeding the hungry and healing the sick, governments will be pressured to suppress "foolish spending" and perform their real job of sustaining the populace. The exploitation of asteroidal resources was mentioned by several participants to be an excellent example of a private sector opportunity. The consensus was to stimulate continued government research investment where history has proved them to be beneficial, but to strongly suggest they permit free enterprise to assume control as early as practicable.

Fundamentally, the most sustainable motivations for continuing space research, exploration, exploitation and colonization are the imagination and the will of humanity. There appears to be enormous enthusiasm among young people which, unfortunately, diminishes as they grow older and attempt to gain a career-supporting education. Even the center of gravity of science fiction which focused on space travel and colonization in the first half of the century has grown bored with these scenarios as "solved problems" and moved on to other arenas such as "cyberspace." The media, particularly television, is intensifying its treatment of space issues this past year, but the consensus of the round table was that the public relations and education of space issues related to the High Frontier needs to be substantially strengthened.