DEFINING NASA'S MISSION AND AMERICA'S VISION FOR THE FUTURE OF SPACE EXPLORATION

HEARINGS

BEFORE THE

SUBCOMMITTEE ON NATIONAL SECURITY, INTERNATIONAL AFFAIRS, AND CRIMINAL JUSTICE

OF THE

COMMITTEE ON GOVERNMENT REFORM AND OVERSIGHT
HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTH CONGRESS

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CONTENTS

DEFINING NASA'S MISSION AND AMERICA'S VISION FOR THE FUTURE OF SPACE EXPLORATION

FRIDAY, MAY 9, 1997

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON NATIONAL SECURITY, INTERNATIONAL AFFAIRS, AND CRIMINAL JUSTICE,
COMMITTEE ON GOVERNMENT REFORM AND OVERSIGHT,
Washington, DC.

The subcommittee met, pursuant to notice, at 8:30 a.m., at the Smithsonian Air and Space Museum, Sixth and Independence Avenue, Washington, DC, Hon. J. Dennis Hastert (chairman of the subcommittee) presiding.

Present: Representatives Hastert, Souder, and Portman.

Also present: Representative Weldon.

Staff present: Robert Charles, staff director and chief counsel; and Ianthe Saylor, clerk.

Mr. HASTERT. The hour of 8:30 having arrived, the Subcommittee on National Security, International Affairs, and Criminal Justice will come to order.

Good morning and welcome. We have a very exciting hearing before us today with some dedicated and thoughtful and generally extraordinary witnesses. Let me say on behalf of the entire subcommittee and all those assembled here, it's a real privilege to have such a spectacular group of witnesses appearing before us today. So gentlemen, thank you very much for giving us your time. I want to thank everyone involved in making this hearing possible, especially the Smithsonian Institute of Air and Space Museum, NASA, and the special witnesses who sit before us this morning.

I'm going to keep my opening statement brief this morning in deference to our distinguished panels. I do want to say a little bit about why we are having this hearing, why we are having it here in the space museum, and why the topic of space and exploration and NASA oversight is a matter of American importance. This national security subcommittee is part of the Government Reform and Oversight Committee of the U.S. House of Representatives. As such, we share oversight responsibility over a number of national security issues and also over NASA.

Let me say that the Science Committee in the U.S. House, under the chairmanship of Congressman Sensenbrenner, and the hard-working Space Subcommittee, chaired by Congressman Rohrabacher, have been and continue to be exceptional leaders in the oversight of NASA. Their work is critical in defining NASA's mission, keeping costs down, and keeping NASA on track—as a matter of fact, just passing out the authorization on NASA recently.

We are trying to move forward through a series of hearings on NASA's vision and America's vision for the future. I believe we may be holding joint hearings on some of these topics, possibly with the Committee on Science. Let me talk about a vision for a moment. In a time of tight budgets, the American Congress and NASA must be ever-conscious of the costs and the benefits of investments made. We also must struggle to truly understand that there are benefits, short-term and long-term, direct and indirect, that come from affordable space science, human space exploration, space-related technologies, aeronautical engineering breakthroughs and, really, the basic education and inspiration of our kids.

These issues, so often forgotten in the public dialog, are a part of what has made this Nation great in the 1960's and 1970's. I can remember as a kid growing up in the 1950's—I date myself—I think of the classic, the 1957 Chevrolet. Everybody remembers that. But as that car came out I also thought—I remember a lot of times standing out in the dark in the corn fields of Illinois, so to speak, watching Sputnik go over.

And the inspiration and the push that that gave us as a country to excel, to move forward, to plan and to achieve. And that is something that we can't forget, we should not forget, and we should not let go of. I think certainly the cores of concerns surrounding the cold war was part of that. And as a Nation we didn't flinch in the face of that mounting threat. We met the challenge. We got the job done. We set our eyes on the Moon, and getting Americans there safely and returning them back to Earth.

And we recognized the importance of mastering space both to our national security and to our long-term future. Let me say that the Air and Space Museum has created a spell-binding display here. To our left—as I understand, this area will open shortly—the display which chronicles the United States-Soviet competition to get to the Moon and to master space also tells another story with long-term implications. It reveals the extraordinary level of cooperation that has characterized United States-Russian relations over the past decade, and the great hope for international cooperation in space that may lie ahead.

And the ahead part of this is what I really want to focus on. In the late 1960's and early 1970's, as this Nation rushed to secure our future in the face of a looming national security threat, we also inspired the world. Not least, we inspired our young people. Young Americans swarmed to the study of math and science and engineering. I think the impact on our youth is important. I wasn't always in Congress. For many years—for 16 years, as a matter of fact, almost two decades—I coached and I taught. And during that period of time I saw what American youth can do if we challenge it.

During the 6 years that I spent in the Illinois legislature I helped to create a math and science academy, because I thought we had to challenge our very best children, our very best kids, and bring them in with our very best teachers so that they could excel. And we hope that some day those graduates of that math and science academy may be taking some of your places. Although those are big shoes to fill, we have to create those types of people to be able to fill those shoes.

In reference, just let me say that the personal computers that we all tap on every day, the microwave ovens, the plastics that preserve our food, the printed circuits, hundreds of medical advances, image technologies from MRI to the CAT scan and thousands of smaller technological advances, including aeronautical design, and advances that make commercial aviation safer, all can be directed directly to the space program.

Let me say that I personally have a commitment to the study of math and science and to the study of space. I hope that we can produce those gifted kids, and those kids have a vision and a dream that they can begin to achieve some of the things that you have worked for and dreamed for also. I, today, would ask that behind us the lunar module mock-up—that's in front of us today—the one that Mr. Aldrin and Neil Armstrong took to the Moon, the command module mock-up, the same type that Mr. Aldrin and Walt flew, is over to our left. The Hubble space telescope, which Mr. Musgrave miraculously fixed on his historic space walk, one of his six space shuttle flights, is also over to our left.

We are privileged to have these astronauts with us today here on our first panel. We are also privileged to have us with us the director of a movie that truly captured the Nation's imagination and caused all of us to skip a few heartbeats from time to time. The film, which many of you have seen, is "Apollo 13," which poignantly retells the triumphant story of the explosion in outer space aboard our Moon-bound *Apollo 13* flight, the flight that carried astronauts Jim Lovell, John Swigert, and Fred Haise.

The movie is a gripping tale of death at the doorstep and disaster at the doorstep of the Apollo program. In speaking of astronauts they'd also say it's one of the most realistic pieces that have probably ever been produced for the American public. They brought those men home safely. And that's what the story of *Apollo 13* is all about. Ron Howard, we're pleased to have you here with us today. This hearing is about the practical oversight of space development but also about the need for vision. As a Nation in Washington, the Speaker of the House has spoken about this, and I look forward today to hearing our outstanding witnesses give their views on this crucial topic. At this time I'd like to ask Mr. Souder if he has any opening statement.

[The prepared statement of Hon. J. Dennis Hastert follows:]

DAN BURTON, INDIANA
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Congress of the United States

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OPENING REMARKS
CHAIRMAN J. DENNIS HASTERT

Subcommittee on National Security, International Affairs, and Criminal Justice

"Defining NASA's Mission and America's Vision for the Future of Space Exploration"

May 9, 1997

We have a very exciting hearing before us today, with some dedicated, thoughtful and genuinely extraordinary witnesses. Let me say, on behalf of the entire Subcommittee and all those assembled here, it is a real privilege to have such a spectacular group of witnesses appearing before us today. And, I want to thank everyone involved in making this hearing possible, especially the Smithsonian Institution's Air & Space Museum, NASA, and the special witnesses who sit before us this morning.

I will keep my opening brief this morning, in deference to our two distinguished panels -- but I do want to say a little bit about why we are having this hearing, why we are having it here, and why the topics of space exploration and NASA oversight matter to America.

This National Security Subcommittee is part of the Government Reform and Oversight Committee of the U.S. House of Representatives. As such, we share oversight responsibility over a number of National Security issues, and also over NASA. Let me say that the Science Committee in the U.S. House, under the Chairmanship of Congressman Sensenbrenner, and the hard work of the Space Subcommittee, chaired by Congressman Rohrabacher, have been -- and continue to be -- exceptional leaders in the oversight of NASA. Their work is critical to defining NASA's mission, keeping costs down, and keeping NASA on track. In fact, as we move forward through a series of hearings on NASA's vision, and America's vision for the future, I believe we may be holding joint hearings on some of these topics.

Let me talk about vision for a moment. In a time of tight budgets, America, Congress and NASA must be ever-conscious of the costs and benefits of investments made. But we must also struggle to truly understand the deep benefits -- short-term and long-term, direct and indirect -- that come from affordable space science, human space exploration, space-related technologies, aeronautical engineering breakthroughs, and the basic education and inspiration of our kids.

These issues, so often forgotten in the public dialogue, are part of what has made this nation great. In the 1960's and early 1970's, this nation responded to the call of a young president, and to the rising chorus of concern surrounding the Cold War. As a nation, we did not flinch, in the face of that mounting threat. Instead, we set our eyes on the moon -- getting Americans there safely and returning them to earth. We recognized the importance of mastering space, both to our national security and to our long-term future.

Let me say that the Air & Space Museum has created a spellbinding display here, to our left, which I understand will open shortly. This display, which chronicles the U.S.-Soviet competition to get to the moon and to master space, also tells another story -- with long-term implications. It reveals the extraordinary level of cooperation that has characterized U.S.-Russian relations over the past decade, and the great hope for international cooperation in space that lies ahead.

And the "ahead" part of all this is what I really want to focus on. In the late 1960's and early 1970's, as this Nation rushed to secure our future in the face of a looming national security threat, we also inspired the world. Not least, we inspired young people. Young Americans swarmed to the study of math, science, and engineering. They thrilled to the discoveries, and were riveted as Buzz Aldrin and Neil Armstrong put their Lunar Module, the Eagle, safely on the surface of the moon -- as Mike Collins orbited the moon and awaited their safe return. I remember those days and the impact that the Apollo program, beginning with the first successful human flight, Apollo 7, flown by Walt Cunningham, Wally Schirra and Donn Eisele, had on our youth. I remember the impact on kids and on American education, because I wasn't always in Congress -- I taught high school for 16 years! This was an inspirational time, and today, we are living -- in part -- off the benefits of that extraordinary national commitment to the sciences, to space and to the future.

For reference, let me just say that the personal computers we all tap on every day, the microwave ovens, the plastics that preserve our food, the printed circuits, hundreds of medical advances, imaging technologies from the MRI to the CATSCAN, and thousands of smaller technological advances -- including aeronautical design advances that make commercial aviation safer and safer -- all can be traced directly to the space program.

Today, we are not drawing kids to this mission or to math and the sciences and engineering the way we did in the late 1960s and 1970s, and one reason is the diffusion and lack of vision that we, as a nation, have allowed ourselves to drift into when it comes to space, space science and space exploration. We need to get back to those basics, and remember that benefits often come after hard work and long-term investment.

What we need to remember is that the generations which follow us must have the benefit of OUR inspiration -- just as we had the benefit of witnessing the courage and dedication, bravery and inspiration of great scientists, engineers and astronauts in the decades that have brought us to this point. Let me say that I personally have a commitment to the study of math and science. In Illinois, when I served in the state legislature, I helped found a special academy for the study of math and science by truly gifted kids; someday, I hope that we have some graduate of that program designing new life support or propulsion systems, finding a cure for cancer, or giving the world some other new advance . But whether that happens or not, the important thing is that we must get back on track with education, and the space program has always been an engine for that end.

Today, fittingly, the Lunar Module mock-up is directly in front of us today -- the one Buzz Aldrin and Neil Armstrong took to the moon. The Command module mock-up -- the same type that Buzz and Walt flew in -- is over to our left. The Hubble Space telescope -- which Story Musgrave miraculously fixed on his historic space walk, on one of his six Space Shuttle flights, is over here to our left also. We are privileged to have these three astronauts with us here today on the first panel.

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So let me stop here and say this in closing. This hearing is about the practical benefits of getting back into space in a big way -- the economic and environmental aspects of clean solar energy from space, the engine of economic growth that lies waiting for us in space-related commercial development, the technologies and medical breakthroughs that so few know about, and the legacy of exploration we will leave for our children. This hearing is about the practical oversight of space development, but also about the need for vision -- as a nation and in Washington. The Speaker of the House has spoken about this, and I look forward today to hearing our outstanding witnesses give their views on this crucial topic.

Mr. HASTERT. Mr. Portman.

Mr. PORTMAN. No.

Mr. HASTERT. Also with us today—we welcome and are very pleased to have with us Dr. Weldon, who represents the Kennedy Space Center. And I know, Doctor, you have an opening statement.

Mr. WELDON. Mr. Chairman and members of the subcommittee, I want to thank you for allowing me to appear with you today. And Chairman Hastert, I want to thank you for calling this hearing and applaud your efforts to give NASA a greater visibility on Capitol Hill and with the public. I also want to thank our very distinguished panelists for taking time from their very busy schedules to be here today.

I know each of you in many ways are probably busier than Congressmen, so it's especially a pleasure to have all of you here and take the time out to make the statement in your support of our Nation's space program. The space coast, which makes up most of my Florida district, includes NASA's Kennedy Space Center, home to our Nation's space shuttle fleet, and the launch site for all U.S. manned missions. It adjoins Cape Canaveral Air Station, which hosts most of our Nation's commercial and military space launches as well as adjoining Patrick Air Force Base, which is home to the U.S. Air Force's 45th Space Wing.

So a love and interest for all things related to space runs through my congressional district. And I have been an outspoken proponent for NASA and our Nation's space efforts. The people of the space program, along with everyone else in our Nation, sit captivated every time we have a launch from Florida. Every year hundreds of thousands of people from across our country and around the world line central Florida's highways and viewing areas to see the space shuttle lift off. The space program motivates our children and inspires scientists, engineers, and explorers who constantly probe the unknown secrets of our world and the universe.

And despite some recent difficulties, NASA is still a symbol of our Nation's preeminent position as a scientific leader in the world. NASA is making important investments in such programs as the international space station, the next generation reusable launch vehicle, which will help the U.S. regain market shares of commercial launches. And NASA is leading the way in search of planets outside our solar system and other scientific endeavors that probe the boundaries of our scientific, medical, and engineering knowledge.

As vice chairman of the Space Subcommittee, I am committed to assuring NASA has the resources it needs to move forward with its mission. We must continue to invest in the space station despite some recent difficulties. And we must continue to safely and efficiently fly the space shuttle fleet. And we must foster the development of reusable launch vehicles which promise to dramatically lower the cost of getting into orbit.

However, we must also balance our human space flight program with a robust and ambitious science and unmanned exploration program. I sat transfixed with the rest of the world in the summer of 1994 when Jupiter was bombarded by the Schumacher-Levi comet, bringing the tiny dimensions of our world into the universal perspective. I anxiously await the data and pictures that our recently launched probe to Mars will bring, as well as the fascinating story that should emerge from our mission to Saturn later this year.

So we need to have a balanced program. Automated probes and robots can serve us well in the initial phases of exploration and to explore where humans may never be able to go. But in order to truly get a sense of the alien world, we have to be there to touch it and feel it. I support a return to the Moon, maybe to stay this time, and a mission to Mars. Technically, we can do these things now. But we must find the political and economic will to make it happen. We must also foster our commercial space sector.

I firmly believe the future of space exploration will depend in a large part on the private sector's role. And I want to give every business an opportunity to use space as an economic resource. We need to take a hard look at how the Federal Government interacts with our commercial space community, and make sure we are not hindering their growth potential.

Finally, I would like to make a point that is very often overlooked in our annual debate on the space program. I support the space program for a variety of reasons, among them the scientific and medical benefits as well as economic growth, international competitiveness, and a stepping stone to future human exploration of the solar system. However, I also strongly believe that our civilization's future lies in space. As you look through history, civilizations that cease to explore and expand their technological frontiers cease to exist. They may choose not to expand and explore for a variety of reasons, but the end result is the same: the civilization stagnates and becomes a part of history. Our Nation and in fact our world is at such a threshold. In space lies the future of the human race. And to turn away from that challenge now could set us back as much as a century or perhaps more. Of course, if we stopped exploring space tomorrow, we probably wouldn't feel the immediate impact. It would come to our children and to our grandchildren, who would lose the drive to explore. And with that would be lost the historic opportunity of our Nation. Mr. Chairman, thank you again for calling this hearing and allowing me to join you today. I hope this can begin a fruitful dialog of the future of our Nation's space program. I look forward to the testimony of the panelists and I thank them for joining us today.

[The prepared statement of Hon. David Weldon follows:]

Opening Statement of

The Honorable Dave Weldon
Vice Chairman, Subcommittee on Space and Aeronautics
Committee on Science

before the

Subcommittee on National Security, International Affairs, and Criminal Justice
Committee on Government Reform and Oversight
U.S. House of Representatives

"NASA and the Future of Space Exploration"

May 9, 1997

Mr. Chairman, Members of the Subcommittee, I want to thank you for allowing me to appear with you today. Chairman Hastert, I want to thank you for calling this hearing and applaud your efforts to give NASA greater visibility on Capitol Hill and with the public. I also want to thank our very distinguished panelists for taking the time to appear today. I know that each of you has an incredibly busy schedule - - probably even busier than a Congressman's - - so your appearance here to talk about a very important subject is deeply appreciated.

The Space Coast - - which makes up most of my Florida Congressional district - - includes NASA's Kennedy Space Center, home to our nation's Space Shuttle fleet and the launch site for all U.S. manned space missions. It adjoins Cape Canaveral Air Station, which hosts most of the nation's commercial and military space launches, and Patrick Air Force Base, which is home to the U.S. Air Force's 45th Space Wing.

So a love and an interest in all things space runs throughout my Congressional district, and I have been an outspoken proponent of NASA and our nation's space effort in every area. The people of the Space Coast, along with everyone else in the nation, sit captivated every time we have a launch from the Cape. Every year hundreds of thousands of people from across the country and around the world line Central Florida's highways and viewing areas to see the Space Shuttle liftoff. The space program motivates our children and inspires scientists, engineers, and explorers who constantly probe the unknown secrets of our world and the universe. And despite some recent difficulties, NASA is still a symbol of our nation's preeminent position as a scientific leader in the world.

NASA is making important investments in such programs as the International Space Station, the next-generation Reusable Launch Vehicle - - which will help the U.S. regain market shares of commercial launches - - a search for planets outside our solar system, and other scientific endeavors that probe the boundaries of our scientific, medical, and engineering knowledge.

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Mr. Chairman, thank you again for calling this hearing and allowing me to join you today. I hope this can begin a fruitful dialogue of the future of our nation's space program, and I look forward to the testimony of our two panels of very distinguished witnesses today. Thank you.

- - end - -

Mr. HASTERT. Dr. Weldon, we certainly appreciate you being here today and your opening statement. Let me add that Tom Barrett, our ranking member from Wisconsin, was very supportive of this hearing, and was not able to make it for personal reasons back in his district. If I may, I'd ask our first panel to stand to be sworn in before I formally introduce each of you in turn.

[Witnesses sworn.]

Mr. HASTERT. Let the record show that the witnesses responded in the affirmative. Please sit down. Now I'd like to formally welcome our first panel. Of course, Dr. Buzz Aldrin is a man who needs no introduction. All of you know that he piloted the lunar module on *Apollo 11,* the first manned mission to the Moon. And he is one of the first men to walk on the Moon. You may also know that Dr. Aldrin was already a war hero before he ever became an astronaut, having flown 66 combat missions in Korea. Also, Dr. Aldrin is a scholar who earned a Ph.D. from MIT for his scientific work on space flight.

Mr. Walt Cunningham was a Marine fighter pilot before coming to the astronauts. He flew the *Apollo 7,* which was the first manned Apollo mission, in 1968. Since then he has built a career as an extremely successful businessman, engineer, and civic leader. We thank you for being with us here today. Mr. Ron Howard, of course, is a well-known actor and movie director who directed the award-winning film, "Apollo 13," along with many other Hollywood blockbusters which I'm sure we've all seen.

And last, but certainly not least, Dr. Story Musgrave is the astronaut who accomplished the daring and successful repair in space of the Hubble telescope. He has flown numerous missions on the space shuttle and has earned academic honors for his work in aerospace, medicine and physiology. We thank you all for coming. Dr. Aldrin, please proceed with you, and be followed by Mr. Cunningham and Mr. Howard and Mr. Musgrave. Thank you very much.

STATEMENTS OF BUZZ ALDRIN, ASTRONAUT, *APOLLO 11;* WALTER CUNNINGHAM, ASTRONAUT, *APOLLO 7;* RON HOWARD, DIRECTOR, "APOLLO 13"; AND STORY MUSGRAVE, ASTRONAUT AND SCIENTIST

Mr. ALDRIN. Thank you very much. Mr. Chairman, Members of Congress, it's a great pleasure for me to be here today. As you know, I have more than a passing interest in space. And I appreciate the chance to say a few words about the possibilities that await this Nation, especially if we make the right choices. I also want to the thank the Air and Space Museum, which has really outdone themselves by allowing this first ever hearing in this great hall.

It's been nearly 30 years since Neil and I walked on the Moon, yet that day is as vivid to me as I know it is to many of you. It was historic in its meaning for all mankind since it was an achievement that Americans and all mankind shared in and continues today. There were a few risks, of course. When we finally set the lunar module down, with Neil piloting and me calling out the number for him, on July 20, 1969, we had only an estimated 16 seconds of fuel left in the descent stage.

On the surface if we had fallen and a suit ripped, there wasn't much chance of surviving that. If the one ascent engine didn't fire or the computers on board malfunctioned, we would never have left the Moon. If the rendezvous with Mike Collins in the command module hadn't gone flawlessly there were other rather unsavory consequences. But the mission was built on the know-how and knowledge of thousands of dedicated Americans.

It was also built on faith and a national commitment. I was fortunate and proud to have been chosen for *Apollo 11.* And I'm here to give back to a Nation that gave me an unparalleled opportunity: the chance to land and walk on the Moon, and to be the first mission ever to do so, and then to continue to carry a message of encouragement for an ever-better future in space.

My message today is also a call for action, a call to all Americans, especially young Americans, to reach out for the stars, reach for greater knowledge, have faith in the future, and help re-inspire a renewed national commitment to human space exploration. First I want to talk a moment about space and about those three words: knowledge, faith and commitment. Then briefly I want to touch on five specific aspects of space flight that beckon us as a Nation.

My chief message is this: America must dream, have the faith to achieve the dream, and develop the fullest possible knowledge of the possibilities that await us. Even the best trained and the brightest engineers, scientists, business people and political leaders, if they have no vision, are mere place holders in time. We must dare again to take risks as a Nation. And we must see again that this generation of Americans—those alive today—have at their fingertips the technology and the recent history necessary to trigger a cascade of vast new discoveries for this living generation and those that will follow.

Some would say that we have an obligation to use the talents and insights that we've been given. Those of us who can remember the power and majesty of the Apollo program's accomplishment, let me say as I sit here before you today, having walked on the Moon, that I am, myself, still awed by that miracle. And I can still remember the feeling of exhilaration as I look here at the lunar module behind me—I recall backing down that ladder to the lunar surface. But that awe in me and each of us were what this Nation and people can bring forth when we try, should be, must be the engine of future achievement, not the slow, dimming light from a time once bright.

It's not the obligation, however, that I wish most to talk about. It's the vision, the faith in brilliant opportunities that await us. These are what bring me here today. In a book that Neil Armstrong, Mike Collins and I wrote in 1970 called "First on the Moon, "Arthur Clarke offered a truly visionary epilogue. Clarke made a number of predictions. Some of those predictions, like the emergence of this space shuttle, reduced payload cost to space, and a satellite-driven communications network as well as other breakthrough technologies, have come true. Others, including routine commercial flight to and from space, space tourism, settlements on the Moon by the early 2000's and human exploration of Mars in our lifetimes are yet to be realized.

But each of these advances requires three things: knowledge, faith, and commitment. Knowledge that we can achieve these feats for all mankind, faith in ourselves, in things larger than ourselves, and in the importance to mankind, that we use the opportunities at our fingertips, and a new found national commitment to do what God has given us the power to do. In short, I'm here today to issue a call for national action.

This is an incredible, uncontainable country: America. We have the power in our national consciousness to dream as few dare to dream, and the power in our national talent pool and convictions to make come true that which we dare to dream. I'm here to say, let the race begin. Let us reawaken America to the power of a compelling dream. And the ability with determination to achieve that dream. And what is the dream of which I am talking? It's John F. Kennedy's dream: to reach the Moon and beyond.

Written in giant letters, giant new steps and leaps. As Kennedy so powerfully said, "We do not do these things because they are easy, but because they are hard." Yes, this is the dream of Arthur Clarke, but also of America's most forward-looking engineers, her proud and growing astronaut corps, and NASA's gifted leadership of men and women. Lighting our way is the legacy left by past greats, names like Wernher Von Braun, Gerry O'Neill, Thomas Paine, and Carl Sagan.

It's the dream of those great and dedicated men and women who were a part of Apollo. But it's also the dream of 1,000 budding American entrepreneurs, who are, at this very moment, laboring to make space flight safe, economical and no less routine than transcontinental air flight. These are men and women of America's private sector. Expanding space flight was Robert Goddard's dream, and the dream of those who made possible Mercury, Gemini, Apollo and the shuttle. And there is more.

The inspiration I want us to willingly embrace today, again, is common to all Americans and all humanity. I know many of you felt it because I've spoken with you. I think those political leaders who feel this inspiration are in sync with America's heartland and with our future. America and her fascination with space is again alive, and we're on the verge of moving again, moving as a Nation, moving the tectonic plates of historic achievement.

I would beckon you to let yourselves dream again. And you may yet hear what I hear ricocheting about the American public: excitement and a willingness to take risks again. Behind that excitement and willingness—a slow, growing call for renewed action. Last month Americans were thrilled to the appearance of the comet Hale-Bopp. They were riveted by a reliving of *Apollo 13's* mission. And let me say here, Ron Howard did a magnificent job in producing that movie, keeping it faithful to the facts. And Americans were even thrilled by memories brought to the surface by when the Star Wars trilogy was re-released earlier this year.

Last month, we also learned that one of Jupiter's moons—Europa—also appears to have an ocean greater in volume than our own and a hot center. And the implications of that discovery are far from small. Yet most Americans don't yet know the best of it. We have within our grasp the technology to get everyday citizens into space routinely and safely for the thrill of a once in a lifetime ride and adventure.

We also have the technology to cost-effectively return to the Moon again. We're even at the threshold of being able to affordably get to Mars with manned missions. And I'm helping NASA and Houston to chart an evolutionary strategy for Mars with very promising, long range sustainability. Let me say this: every American whose heart beats faster at the news of possible water on the Moon or possible life on Mars or when they hear of an affordable lottery ticket into space for the fun of it, or the chance to safely visit orbiting space resorts: a trip that will soon be no less safe than driving cross-country to see the Nation's marvelous Air and Space Museum.

These Americans know what I'm talking about. So I say let us join together as a Nation undivided, and reawaken these wonderful and achievable dreams. Let us dare to think about the future. Let's talk again about a permanent presence on the Moon and sustained interplanetary travel with all it's discoveries. Let's draw up the plans and let's begin the investment. These events are achievable. And perhaps, if you look closely at the largely unknown advances we've made since *Apollo 11,* even within our lifetime.

Let's think again as we did in the 1960's as a great and ambitious Nation remembering cost efficiencies, but having faith and a renewed commitment to explore and experience space and its richness. Today we have the knowledge and technology to tap unlimited energy potential in near Earth space and unimaginable resource potential beyond. Indeed, last week was historic for Congress's balanced budget success. And I congratulate Congress with the vision that it took to achieve that success.

But imagine having space-based solar energy assets and space-based resources that truly keep this planet pollution free and make budget deficits literally unthinkable by their shear richness. That's what awaits us if we make the right investments. The future I allude to has yet to be built. But all this is not fiction. It's very close to being fact. A clean, green, non-polluted Earth drawing on abundant space-tapped energy from our Sun, passenger travel to and from space for commercial and adventure activity, the step by step advance to Mars, even low-cost cycling missions to and from that planet and then beyond.

All these goals are worth pursuing and well within our grasp. Once more, they will reenergize this Nation, and if Apollo is any example, spur rippling economic growth. You know the Apollo program's miraculous achievements were built on a dream by this Nation's leaders and our people. Let us take stock of ourselves and our place in history of mankind. And let us not be timid or content to rest on our laurels. Already a generation has passed since we walked on the Moon. I will say it again, and pray, as I did when we sat on the Moon, that we can start this engine.

Greatness requires knowledge, faith and commitment. The investment in public determination to reawaken the dream will start here with Congress and today's leaders. Before closing I want to touch on several specifics. And on questioning I'll gladly go into more detail.

First, refinding the inspiration that we had in Apollo and that the entire Nation had. Reawakening the dream is vital for America's children; for your children and my children. I need only note that America's children flocked to math and science in the era of Apollo, both during and after those historic missions. Since then there has been a clear erosion of our inspiration and fascination, the curiosity and the calling of science, and especially the countless sciences tied to space and space flight.

We can and must re-inspire our children. We live through historic achievement based on well trained minds. They should have that experience. And their generation should have the reservoir of that training for their sake and the Nation's.

Second, I think we have to get serious about investing in the best next generation reusable space transportation options. There are several options. And they're all worth study and investment. One I'll briefly allude to, however, is the so-called Star Booster two-stage deliverer. The common sense of this approach and the economical nature of the investment cannot be oversold. And I'll gladly get into more of this on questioning or after.

Third, I cannot stress the nearness and excitement that surrounds giving every American a real shot at getting into space safely and for the pleasure of that experience. I call it the drive for space tourism because that's what it is. The investments are already being made. And we need chiefly to support them with complementary efforts at NASA and a general reduction in outdated regulations restricting private sector rocketry and space exploration.

Fourth, we must again look seriously at and invest in technologies which support, both at NASA and in the private sector, manned missions and a permanent presence on the Moon. There are endless spinoff and commercial development arguments for this investment. But the one argument that I feel is most compelling is, the mission is larger than ourselves. We were called together as a Nation and as a species by the Apollo missions to the Moon. And there is simply no measure of the good that these explorations brought to us all, not least by bringing the global community closer together.

Finally, the importance of now seriously looking at and investing in manned missions to Mars leading toward permanent sustainability there could not be greater. The time is upon us to move into the investment stage and to look at making practical the technologies that we know have, but could only have dreamed of in the 1970's. We can do this. And we must free the private sector from regulations that hamper the sort of experimentation that will make this a reality. Even as we support NASA's research and development we must reach out and do what we're able to do. And we can do this within our lifetimes.

In closing, let me say that space is our final frontier. And that frontiers are essential for the advance of humanity and for advance of individuals within the community of man. Our children will thrill to the achievements we set forth to achieve, and we can achieve them if we are willing to dream, to embrace the knowledge, faith and commitment, and to relight that engine which will take us all first into space, then to the Moon and Mars, and, finally, to the stars. As I like to say with my feet firmly on the ground, on Earth today, as surely as they were on the Moon nearly 30 years ago, let's join together and shoot for the stars, ad astra. Thank you, Mr. Chairman.

[The prepared statement of Mr. Aldrin follows:]

TESTIMONY OF BUZZ ALDRIN,
LUNAR MODULE PILOT, APOLLO 11

Mr. Chairman, Members of Congress and others, it is a great privilege to have been called here today. As you know, I have more than a passing interest in space, and I appreciate the chance to say a few words about the possibilities that await this nation -- especially if we make the right choices ... I also want to thank the Air & Space Museum, which has really outdone themselves by allowing this first-ever hearing in this great hall.

It has been nearly thirty years since Neil and I walked on the moon. Yet that day is as vivid to me as I know it is to many of you. It was historic, and it's meaning for all mankind -- since it was an achievement that Americans and all mankind shared in -- continues today.

There were a few risks, of course. When we finally set the lunar module down -- with Neil piloting and me calling the numbers -- on July 20, 1969, we had only an estimated 16 seconds of fuel left for descent. If we fell, and a suit ripped, there wasn't much chance of surviving that. If the one ascent engine didn't fire, or the computers on board malfunctioned, we would never have left the moon. If the rendezvous with Mike Collins in the Command Module hadn't gone flawlessly, there were other rather unsavory consequences. But the mission was built on the know-how and knowledge of thousands of dedicated Americans; it was also built on faith and a national commitment.

I was fortunate and proud to be chosen for Apollo 11, and I am here to give back what I can to a nation that gave me an unparalleled opportunity -- the chance to land and walk on the moon -- and to be the first mission ever to do so, and then to continue to carry a message of encouragement for an ever-better future in space.

My message today, is also a call to action -- a call to all Americans -- especially young Americans -- to reach out for the stars, reach for greater knowledge, have faith in the future, and help re-inspire a renewed national commitment to human space exploration.

First, I want to talk a moment about space and about those three words -- knowledge, faith and commitment. Then, briefly, I want to touch on five specific aspects of space flight that beckon us, as a nation.

My chief message is this: America must again dream, have the faith to achieve the dream, and develop the fullest possible knowledge of the possibilities that await.

Even the best trained and brightest engineers, scientists, business people, and political leaders -- if they have no vision -- are mere placeholders in time. We must dare again to take risks as a nation, and we must see again that this generation of Americans -- those alive today -- have at their fingertips the technology and recent history necessary to trigger a cascade of vast new discoveries ... for this living generation and those that will follow.

Some would say that we have an obligation to use the talents and insights we have been given -- those of us who can remember the power and majesty of the Apollo program's accomplishments. Let me say, as I sit here before you today -- having walked on the moon -- that I am myself still awed by that miracle. And I can still remember the feeling of exhilaration as I look here at the Lunar Module behind me, and recall backing down that ladder to the lunar surface [motion toward LEM]. But that awe -- in me and in each of us -- for what this nation and people can bring forth when we try, should be -- must be -- the engine of future achievement, not a slow-dimming light from a time once bright.

It is not the obligation, however, that I wish most to talk about. It is the vision -- the faith and brilliant opportunities that await us. These are what bring me here today.

In a book that Neil Armstrong, Mike Collins and I wrote in 1970, called First on the Moon, Arthur Clarke offered a truly visionary epilogue.

Clarke made a number of predictions. Some of those predictions, like the emergence of the Space Shuttle, reduced payload costs to space, and a satellite-driven communications network, as well as other breakthrough technologies, have come true.

Others -- including routine commercial flight to and from space, space tourism, settlements on the moon by the early 2000's, and human exploration of Mars in our lifetimes -- are yet to be realized.

But each of these advances requires three things - knowledge, faith and commitment. Knowledge that we can achieve these feats for all mankind, faith in ourselves, in things larger than ourselves and in the importance to mankind that we use the opportunities at our fingertips, and a new-found national commitment to do what God has given us the power to do.

In short, I am here today to issue a call for national action. This is an incredible, uncontainable country -- America. We have the power in our national consciousness to dream as few dare to dream, and the power in our national talent pool and convictions to make come true that which we dare to dream. I am here to say: Let the race begin. Let us reawaken America to the power of a compelling dream, and the ability -- with determination -- to achieve that dream.

And what is the dream of which I am talking? It is John F. Kennedy's dream -- to reach the moon and beyond -- written in giant letters, new giant leaps. As Kennedy so powerfully said, "we do not do these things because they are easy, but because they are hard." Yes, this is the dream of Arthur Clarke, but also of America's most forward-looking engineers, Her proud and growing astronaut corps, and NASA's gifted leadership and men and women. Lighting our way is the Legacy left by past greats, names like Wernher von Braun, Gerry O'Neill, Thomas Paine, and Carl Sagan.

It is the dream of those great and dedicated men and women who were a part of Apollo. But is it also the dream of a thousand budding American entrepreneurs, who are -- at this very moment -- laboring to make space flight safe, economical and no less routine than transcontinental air flight. These are men and women of America's private sector. Expanding space flight was Robert Goddard's dream, and the dream of those who made possible Mercury, Gemini, Apollo and the Shuttle.

And there is more. The inspiration I want us to willingly embrace again is common to all Americans, and all humanity. I know many of you feel it, because I have spoken with you. I think those political leaders who feel this inspiration are in sync with America's heartland - and with our future.

America, and Her fascination with space is again alive, and we are on the verge of moving again -- moving as a Nation, moving the tectonic plates of historic achievement.

I would beckon you to let yourselves dream again, and you may yet hear what I hear ricochetting about the American public: Excitement and a willingness to take risks again -- behind that excitement and willingness, a slow-growing call for renewed action.

Last month, Americans were thrilled to the appearance of the Comet Hale-Bopp ... They were riveted by a re-living of Apollo 13's mission -- and let me say, here, Ron Howard did a splendid job producing that movie, keeping it faithful to the facts ... And Americans were even thrilled by memories brought to the surface when the Star Wars trilogy was re-released earlier this year.

Last month, we also learned that one of Jupiter's moons, Eurpoa, appears to have an ocean greater in volume than our own, and a hot center -- the implications of that discovery are far from small.

Yet, most Americans don't yet know the best of it -- we have within our grasp the technology tog et everyday citizens into space routinely and safely for the thrill of a once in a lifetime rise and adventure. We also have the technology to cost-effectively return to the moon again. We are even at the threshold of being able to affordably get to Mars with manned missions, and I am helping NASA in Houston to chart an evolutionary strategy for Mars, with very promising, long-range sustainability.

Let me say this: Every American whose heart beats faster at the news of possible water on the moon, or possible life on Mars, or when they hear of an affordable lottery ticket into space for the fun of it, or the chance to safely visit orbiting space resorts -- a trip that will soon be no less safe than driving cross country to see the Nation's marvelous Air & Space Museum -- these Americans know what I am talking about. So, I say, let us join together again, as a Nation undivided, and re-awaken these wonderful and achievable dreams.

Let's dare to think about the future. Let's talk again about a permanent presence of the moon, and sustained inter-planetary travel with all its discoveries. Let's draw up the plans, and let's begin the investment. These events are achievable -- and perhaps, if you look closely at the largely unknown advances we have made since Apollo 11, even within our own lifetimes.

Let's think again as we did in the 1960s -- as a great and ambitious nation, remembering cost-efficiencies, but having faith and a renewed commitment to explore and experience space and its richness.

Today, we have the knowledge and technology to tap unlimited energy potential in near-earth space and unimaginable resource potential beyond. Indeed, last week was historic for Congress' balanced budget success -- and I congratulate Congress for the vision it took to achieve that success -- but imagine having space-based solar energy assets and space-based resources that truly keep this planet pollution-free and make budget deficits literally unthinkable -- by their sheer richness. That's what awaits us, if we make the right investments.

The future I allude to has yet to be built. But all this is not fiction; it is very close to being fact -- a clean, green, non-polluted earth drawing on abundant, space-tapped energy from our sun ... passenger travel to and from space for commercial and adventure activity ... the step-by-step advance to Mars, even low-cost cycling missions to and from that planet, and then beyond. Al these goals are worth pursuing, and well within our grasp. What is more, they will re-energize this nation, and -- if Apollo is any example -- spur rippling economic growth.

You know, the Apollo program's miraculous achievements were built on a dream by this Nation's leaders and our people. Let us take stock of ourselves and our place in the history of mankind -- and let us not be timid or content to rest on our laurels. Already, a generation has passed since we walked on the moon.

I will say it again, and pray -- as I did when we sat on the moon -- that we can start this engine. Greatness requires knowledge, faith and commitment. The investment and public determination to get re-awaken the dream will start here, with Congress and today's leaders.

Before closing, I want to touch on several specifics. On questioning, I will gladly go into more detail on each.

First, re-finding the inspiration that we had in Apollo, and that the entire Nation had -- re-awakening the dream -- is vital for America's children, for your children and my children. I need only note that America's children flocked to math and sciences in the era of Apollo, both during and after those historic missions.

Since then, there has been a clear erosion of the inspiration and fascination, the curiosity and calling, of science -- and especially the countless sciences tied to space and space flight. We can and must re-inspire our children. We lived through historic achievements, based on well-trained minds; they should have that experience and their generation should have the reservoir of that training, for their sake and the Nation's.

Second, I think we have to get serious about investing in the best possible next-generation reusable space transportation options. There are several options, and they are all worth study and investment. One I will briefly allude to, however, is the so-called Star Booster. The common sense of this approach, and the economical nature of the investment cannot be oversold. And I will gladly get more into this on questioning.

Third, I cannot stress the nearness and excitement that surrounds giving every American a real shot at getting into space safely and for the pleasure of that experience. I call it the drive for space tourism, because that is what it is. The investments are already being made, and we need chiefly to support them with complementary efforts at NASA, and a general reduction of outdated regulations restricting private sector rocketry and space exploration.

Fourth, we must again look seriously at, and invest in technologies which support -- both at NASA and in the private sector -- manned moon missions and a permanent presence on the moon. There are endless spin-off and commercial development arguments for this investment. But the one argument that I feel is most compelling is the mission larger than ourselves; we were called together as a nation, and as a species, by the Apollo missions to the moon. And there is simply no measure of the good that these explorations brought to us all, not least by bringing the global community closer together.

Fifth, and finally, the importance of now seriously looking at and investing in a manned mission to Mars could not be greater. The time is upon us to move into the investment phase, and to look at making practical the technologies that we now have, but could only have dreamed of in the 1970's. We can do this, and we must free the private sector from regulations that hamper the sort of experimentation that will make this a reality, even as we support NASA's research and development. We must reach out and do what we are able to do, and we can do this within our lifetimes.

In closing, let me say that Space IS our final frontier, and that frontiers are essential for the advance of humanity, and for advance of individuals within the community of Man. Our children will thrill to the achievements we set forth to achieve, and we can achieve them -- if we are willing to dream, to embrace the knowledge, faith and commitment -- and to re-light that engine which will take us all first into space, then to the moon and Mars, and finally toward the stars. As I like to say, with my feet firmly on the ground -- on Earth today, as surely as they were on the moon nearly thirty years ago -- let us join together and shoot for the stars, ad astra.

Mr. HASTERT. Thank you, Dr. Aldrin. At this time, Mr. Cunningham.

Mr. CUNNINGHAM. Thank you, Mr. Chairman and members of the subcommittee. You do me honor by inviting me to share my thoughts with you here this morning. And it's a pleasure to be here with my associates. Buzz and I entered the space program the same day. Story Musgrave, who bridges the period between the golden age of manned space flight—Apollo—and the current shuttle era. As we sit here amongst the artifacts of the golden age of manned space flight, I would like to talk a little bit about a movement which has been away from the chance of dangerous adventure and toward a risk-free society.

In 1961 President John F. Kennedy announced to the world: "We will land a man on the Moon and return him safely to Earth in this decade. We choose to do this not because it is easy but because it is hard." What a truly audacious statement. At that time not a single American had yet been into orbit. It took vision, initiative, leadership. It took someone willing to stick their neck out, someone willing to risk failing.

Economic problems and social progress were serious issues in 1961, too, much as they are today. So was the budget. President Kennedy knew that even in hard times you cannot take your eyes off of the future. While responding to the needs of today we must also invest in tomorrow. Today man's landing on the Moon is history. Against enormous odds, with the whole world watching, a group of engineers, scientists and managers accepted the challenge, took a risk, and changed the way that we perceive our world. And incidentally, they kept the spirit of adventure alive for one more generation.

We went after Moon rocks. But the real payoff was probably a surprise to all of us. The real payoff was what happened to us back on Earth. Apollo changed all of us inside. For a brief period during the time of Apollo, our society felt good about itself again. We felt together. The Moon landings proudly proclaimed to others that we accepted no limits on what we could accomplish. Yes, we knew it was risky. But there was never any doubt that the potential gain greatly exceeded the risk. And success carried with it the promise that our children and our grandchildren would be exploring the frontiers of the universe.

After *Apollo 11* in 1969, Australian Prime Minister Jack Gordon put it very nicely, I thought, in his message which said, among other things—he ended up by saying, "May the high courage and technical genius which made this achievement possible be so used in the future that mankind will live in a universe in which peace, self-expression, and the chance of dangerous adventure are available to all." What a wonderful dream.

In the past 28 years, what has happened to that chance of dangerous adventure? Today the once rambunctious American spirit of innovation and adventure is being paralyzed by the desire for a risk-free society. Security and a risk-free existence have replaced opportunity and the chance of dangerous adventure as the goal of most Americans. What has happened to the sense of dedication, commitment, the stick-to-it-iveness; the spirit of adventure that made us great? Are we doomed to a future where our resources will be used only to feed our existence and never for dreaming and reaching?

This country was established by risk takers. Without risk takers there would be no U.S. Constitution today. The 56 men who signed that amazing document knew they were risking death when they pledged their fortunes, their lives and their sacred honor to achieve independence. And this country was built by those who met a challenge and accepted the risk, not cautious nay-sayers, built by those who wanted to live, not simply exist. It's the Christopher Columbuses and the Neil Armstrongs who move us forward, not the Ralph Naders. With a Ralph Nader at the head of a wagon train we would never have made it across the plains and over the Rockies.

Today we hear incessant talk of limits, usually expressed as a shortage of funds. Any grand aspirations we might have are at the mercy of political institutions: some of the most risk-averse groups in our society. Our only real limits are those we place on ourselves. In a country which has survived many crises, none has been more important than the current crisis of will. Today we fail not because of our inability to do something, we fail because our unwillingness to tackle it in the first place. We are simply unwilling to take the risk.

The Apollo program was a catalyst to education for a whole generation of students. The inspiration of another grand objective is as important to this generation as the successful implementation of Apollo was to America in the 1960's. But we have ducked such a commitment. And education has been on a downhill slide for years. We do a further disservice to today's students: our next generation of leaders. The relationship between challenge, risk and, responsibility and leadership is also being neglected. Leadership requires confidence in oneself before you can instill confidence in others.

And how can you have self confidence if you have avoided risk all your life? I believe every generation has an obligation to take some risks, to raise society to some higher plateau, to free men's minds for a look at new worlds. The society which does not utilize its knowledge and capabilities to push back boundaries begins to decline and is replaced by those societies which do utilize their capabilities.

A good example: at the height of its glory the Chinese fleet sailed for India 60 years prior to Columbus' search for India. The Emperor called the fleet back and burned it. China, to this day, has not returned to position as significant world power. America is at a crossroads. Are we to maintain our technological leadership and invest in our future or will mire ourselves solely in the problems of today and squander our future? The choice is ours. Let us acknowledge that the chance of dangerous adventure is a basic need of the human spirit, and commit this to a new grand challenge.

In the next century no one will care how carefully and cautiously we survived the last third of the 20th Century. But they will celebrate our willingness to accept risk, to make a commitment to expand our universe and to change forever the way we looked at our world when we decided to land a man on the Moon. You and I cannot set foot on distant planets, but we can set our minds on the future, and, perhaps, return to a society where peace, self expression and the chance of dangerous adventure are available to all.

I have taken the liberty of outlining a space policy that meets those needs. The full text is available to you, gentleman. But I summarize here just the principle points before I compete. America has lost the vision of its role in space. We have forgotten why we go into space and what benefits we derive from space exploration. For the past 35 years the space program has been a primary change engine for American technological advance. These advances have fed the private sector in their search for commercial applications and thereby added to our economic strength.

What is desperately needed now is a clearly defined, easily understood and consistent policy for U.S. space activities. Point No. 1: preeminence in space as a national policy. Preeminence among the space faring nations of the world requires but one thing—that we decide to do it. This can only occur if it a matter of national policy. No. 2: a long range goal for NASA. A national space policy should encompass NASA, the private sector, and to some degree the Department of Defense. It should promote not only the exploration of the heavens but also the defense of America. NASA's long range goal should be no less then the exploration of our solar system. This goal bypasses the problem of repeatedly having to sell new starts. It embraces both manned and unmanned activities.

No. 3: the space station is a good start. It's value, however, as an inspirational agent has been compromised by wavering commitment, dragged out funding, and turning it into a foreign policy program. No. 4: space funding—excuse me, I didn't finish with point No. 3. International partnerships should be based on substance, not appearance and not politics. And we shouldn't have to subsidize our partners.

No. 4: space funding must be both adequate and predictable. Predictable Federal funding is essential if the private sector is expected to make future commitments and long range plans. NASA should stop overselling programs at their inception and Congress should be realistic about accepting the true cost of achievement and leadership. No. 5: space research and development is an investment. Space research and development funding is not in direct competition with entitlement programs. It is an investment which keeps America prosperous, and is vital, and enables us to support entitlement programs.

No. 6: assured access to space through a balanced launch fleet. America should balance the access to space provided by the space shuttle with programs to develop expendable launch vehicles and a new heavy lift vehicle.

No. 7: space and national defense. A national space program has a legitimate and vital role to play in the future defense of this Nation just as railroads, shipping and aviation did once they came into being. The overall military space program, per se should not be treated not as space policy issue but as a military defense issue.

No. 8: cooperative ventures. One characteristic of U.S. leadership in space has been its openness to international cooperation. In the future, such cooperation should be based on equitable contribution as well as equitable return. It should capitalize on the unique strengths of each partner with each partner carrying his own load.

No loss leaders. No. 9: strong leadership and clear priorities are required. A personal commitment from the President, whomever that may be, is paramount, but requires Congress for approval and funding.

NASA, the private sector, and the Pentagon must be challenged to accomplish it. The program must be clearly communicated to the American people who must subscribe to it. Everything possible should be done to prevent space disasters. But we must be willing to persevere in spite of disasters and risks. Those are my nine points. I'll just finish by saying it is time for another leap forward for mankind. Commitment to any policy costs money. We are all aware of the current budget constraints. Congress, in meeting their obligation to the present should not forget their obligation to the future as well. Thank you.

[The prepared statement of Mr. Cunningham follows:]

FROM THE CHANCE OF DANGEROUS ADVENTURE TO A RISK-FREE SOCIETY

Walter Cunningham, Astronaut, Apollo VII

In 1961, President John F. Kennedy announced to the world, "We will land a man on the moon and return him safely to earth in this decade. We choose to do this not because it is easy but because it is hard."

What an audacious statement! At that time not a single American had yet been in orbit. It took vision, initiative and leadership. It took someone willing to stick their neck out - someone willing to risk failing. Economic problems and social progress were serious issues in 1961, too -- much as they are today. So was the budget. President Kennedy knew that even in hard times you cannot take your eyes off the future. While responding to the needs of today -- we must also invest in tomorrow.

Today, man's landing on the moon is history. Against enormous odds with the whole world watching a group of engineers, scientists and managers accepted a challenge, took a risk, and changed the way we perceived our world. And not incidentally, kept the spirit of adventure alive for one more generation.

We went after moon rocks but the real payoff was probably a surprise to all of us. The real payoff was what happened to us back here on earth. Apollo changed all of us -- inside. For a brief period during the Time of Apollo, our society felt good about itself again; we felt together. The moon landings proudly proclaimed to others that we accepted no limits on what we could accomplish.

Yes, we knew it was risky. But there was never any doubt that the potential gain greatly exceeded the risk. And success carried with it the promise that our children and our grandchildren would be exploring the frontiers of the universe.

After Apollo 11 in 1969, Australian Prime Minister Gorton put it nicely when he said, ". . . May the high courage and technical genius which made this achievement possible be so used in the future that mankind will live in a universe in which peace, self-expression and the *chance of dangerous adventure* are available to all."

In the past 25 years, what has happened to that "*chance of dangerous adventure*"?

Today, the once rambunctious American spirit of innovation and adventure is being paralyzed by the desire for a risk free society. Security and a risk-free existence have replaced opportunity and the chance of dangerous adventure as the goal of most Americans. What has happened to the sense of dedication, commitment, the stick-to-itiveness, the spirit of adventure that made us great? Are we doomed to a future where our resources will be used only to feed our existence and never for dreaming and reaching?

This country was established by risk-takers. Without risk-takers there would be no United States Constitution today. The 56 men who signed that amazing document knew they were risking death when they pledged "their fortunes, their lives, and their sacred honor" to achieve independence. And this country was built by those who met a challenge and accepted the risk - not cautious nay-sayers; by those who wanted to live, not simply exist. It's the Christopher Columbuses and the Neil Armstrongs who move us forward, not the Ralph Naders. With a Ralph Nader at the head of a wagon train, we would never have made it across the plains and over the Rockies.

Today, we hear incessant talk of limits, usually expressed as a shortage of funds. Any grand aspirations we might have are at the mercy of political institutions, some of the most risk-averse groups in our society. Our only real limits are those we place on ourselves! In a country which has survived many crises, none has been more important than our current crisis of will. Today, we fail not because of our inability to do something; we fail because of our unwillingness to tackle it in the first place. We are simply unwilling to take the risk.

The Apollo Program was a catalyst to education for a whole generation of students. The inspiration of another grand objective is as important to this generation as the successful implementation of Apollo was to America in the sixties. But we have ducked such a commitment and education has been on a down hill slide for years.

We do a further disservice to today's students -- our next generation of leaders -- as well. The relationship between challenge, risk, responsibility and leadership is also being neglected. Leadership requires confidence in one's self before you can instill confidence in others. And how can you have self confidence if you have avoided risk all your life?

I believe every generation has an obligation to take some risks, to raise society to some higher plateau, to free men's minds for look at new worlds. The society which does not utilize its know-ledge and capabilities to push back boundaries begins to decline and is replaced by those societies which do utilize their capabilities.

A good example: At the height of its glory the Chinese fleet sailed for India 60 years prior to Columbus search for India. The Emperor called the fleet back and burned it. China, to this day, has not returned to a position of significant world power.

America is at a crossroads. Are we to maintain our technological leadership and invest in our future or will we mire ourselves solely in the problems of the day and squander our future? The choice is ours. Let us acknowledge that *the chance of dangerous adventure* is a basic need of the human spirit and commit this country to a new grand challenge.

In the next century, no one will care how carefully and cautiously we survived the last third of the twentieth century. But they will celebrate our willingness to accept risk, to make a commitment, to expand our universe and to change forever the way we looked at our world when we decided to land a man on the moon. You and I can not set foot on distant planets but we can set our minds on the future and, perhaps, return to a society where peace, self expression, and *the chance of dangerous adventure* are available to all.

I have taken the liberty to outline a space policy which I believe meets these needs. Copies of the complete document are available and I summarize only the principal points here.

SPACE POLICY SUMMARY

America has lost the vision of its role in space. We have forgotten why we go into space and what benefits we derive from space exploration.

U.S. Pre-Eminence: A Rationale

For the past 35 years, the space program has been a primary "change engine" for American technical advance. These advances have fed the private sector in their search for commercial applications, and thereby added to our economic strength. What is desperately needed is a clearly defined, easily understood and consistent policy for U.S. space activities.

1. Pre-Eminence In Space As National Policy

Pre-eminence among the space faring nations of the world requires but one thing - THAT WE DECIDE TO DO IT. That can only occur if it is a matter of national policy!

2. Long Range Goal For NASA

A national space policy should encompass NASA, the private sector and, to some degree, the Department Of Defense. It should promote not only the exploration of the heavens but also the defense of America. NASA's long range goal should be no less than: **The Exploration of Our Solar System**. This goal bypasses the problem of repeatedly having to sell "new starts". It embraces both manned and unmanned activities

3. The Space Station Is A Good Start

International partnerships should be based on substance, not appearance and not politics. And we shouldn't have to subsidize our partners.

4. Space Funding Must Be Both Adequate And Predictable

Predictable federal funding is essential if the private sector is expected to make future commitments and long range plans. NASA should stop overselling programs at their inception and Congress should be realistic about the cost of achievement and leadership.

5. Space Research And Development Is An Investment

Space research and development funding is NOT in direct competition with entitlement programs. It as an investment which keeps America prosperous and vital and enables us to support entitlement programs.

6. Assured Access To Space Through A Balanced Launch Fleet

America should balance the access to space provided by the space shuttle with programs to develop expendable launch vehicles and a new heavy lift vehicle.

7. Space And National Defense

A national space program has a legitimate and vital role to play in the future defense of this nation just as railroads and shipping did once they came into being. The overall military space program, per se, should be treated not as space policy issue but as a military/defense issue.

8. Cooperative Ventures

One characteristic of U.S. leadership in space has been its openness to international cooperation. In the future, such cooperation should be based on equitable contribution as well as return. It should capitalize on the unique strengths of each partner with each partner carrying his own load – no "loss leaders"

9. Strong Leadership And Clear Priorities Are Required

A personal commitment from the President (whomever that may be) is paramount. But it requires Congress for approval and funding. NASA, the private sector and the Pentagon must be challenged to accomplish it. The program must be clearly communicated to the American people who must subscribe to it. Everything possible should be done to prevent space disasters BUT we must be willing to persevere in spite of disasters and risks.

It is time for another leap forward for mankind! Commitment to any policy costs money and we are all aware of the current budget constraints. Congress, in meeting their obligation to the present should not forget their obligation to take a responsible approach to the future as well.

UNITED STATES SPACE POLICY -- A PROPOSAL

Walter Cunningham, Astronaut, Apollo VII

America has lost the vision of its role in space. We have forgotten why we go into space and what benefits we derive from space exploration.

U.S. PRE-EMINENCE: A RATIONALE

In the past thirty years, America has invested over $200 billion in becoming the world's technological leader in space science and applications. As a nation, we cannot afford to relinquish what has been so hard earned. And yet, we seem unable or unwilling to exploit the knowledge and expertise for which we've already paid.

America is a technology driven nation, willing to maintain our position in the world more by its wits than its brawn. But, we can only sustain the technical leadership we have achieved by aggressively pushing back the frontiers and working at the leading edge of scientific boundaries.

Historically, the Federal Government has borne the brunt of research and development costs - especially in basic research. This has been accomplished most effectively through funding major programs (so called, "Engines of Change") requiring the development of new knowledge across a broad range of scientific and technical disciplines. For the past 35 years, the space program has been a primary "change engine" for American technical advance.

These advances have fed the private sector in their search for commercial applications, and thereby added to our economic strength. Outlined below are several reasons for America to maintain the high ground in space development; to reaffirm pre-eminence in space as a national priority; and to commit national resources to a comprehensive space policy.

1. PRE-EMINENCE IN SPACE AS NATIONAL POLICY

Today, America is at a crossroads. We are challenged to maintain pre-eminence among the modern space faring nations of the world. America is suffering not from a lack of ability nor of our technology but from an unwillingness to try. Pre-eminence requires but one thing - THAT WE DECIDE TO DO IT.

Our commitment cannot be tied to a long over "space race", to teflon frying pans or near-term commercial profits. And it is time we quit looking at the space program as some form of luxury - a place where we travel for adventure and, just maybe, scientific research.

Science and technology provide the fundamental knowledge that leads to national strength and prestige. Ambitious space goals (like Apollo) force major advances over a broad spectrum of technologies that ultimately touch all aspects of our nation's economic and social life.

In advocating space leadership, the payoff is not in the prestige nor the plaudits of other nations but in the technological leaps - the advances of several decades compressed into one - which accrue to the nation with the commitment and determination to pursue them.

Maintaining a position of leadership among the space faring nations of the world must be a matter of national policy!

National policy is a reason well understood by Russia, France, China, Japan and others. These nations see space as an indispensable arena for scientific, industrial and national security activities.

2. LONG RANGE GOAL FOR NASA

America has the very best technology but have not yet demonstrated the commitment to establish long term goals and stick to them. What is desperately needed is a clearly defined, easily understood and consistent policy for U.S. space activities - a policy that encompasses NASA, the private sector and, to some degree, the Department Of Defense. Our space policy should promote not only the exploration of the heavens but also the defense of America.

NASA's long range goal should be no less than: **The Exploration of Our Solar System**. This goal will capture the public's imagination and accelerate space education. Our future success in this arena depends on the space program's appeal to our brightest minds facing a challenge worthy of their best efforts.

Policy elements should be clearly enunciated; e.g. the International Space Station as a milestone on the road to exploration of the solar system. Manned exploration of Mars should be another milestone even though it will not be achieved during the next administration nor of the following nor of the one after that. But this administration and this Congress could leave office feeling good about establishing a long range goal and giving better focus to a key agency, NASA.

The space program should avoid the appearance of any particular project or program being an end in itself, forcing the country into the position of repeatedly having to sell "new starts". When the "goal" of the Apollo Program was accomplished, NASA went back to the starting point. When the Eagle landed, America began its withdrawal from space as a national priority.

Focusing on exploration of our solar system transcends the selection of a Moon base, or a manned Mars expedition; or simply endorsing NASA's present position. It embraces both manned and unmanned activities; for both will be needed. "Exploration of The Solar System" is a goal that secures the technical high ground and displays leadership. Against such a goal, the Moon or Mars Programs become tactical objectives evaluated according to their contribution to achieving that goal.

Leadership for NASA should be reviewed to insure that the best qualified and available leaders are sought out and given the opportunity to serve the country, the mission, and the dedicated people in NASA and their support contractors

3. THE SPACE STATION IS A GOOD START

The space station will function as a research center in orbit, a manufacturing facility, a servicing facility for manned satellites, a facility for long term observation of the earth and heavens, a space transportation node for higher orbits - the moon and deep space, an assembly facility for large space structures and a storage facility for spares, consumer goods and satellites.

In this national laboratory in space, advanced technology, materials and products which cannot be produced on earth will be made possible by utilizing unique properties of the space environment. Commercial exploitation in materials processing of pharmaceuticals, new alloys, polymers, ceramics, sensors, semi-conductor crystals and other high value materials can begin. A competitive position in a global marketplace is at stake.

The Space Station will have a pervasive effect on technology of the next generation, and will help to maintain our reputation as the leading technological nation of the world.

The Space Station Program is also an excellent opportunity for international cooperation on a meaningful basis. The benefits to our international partners and ourselves are real, and include the assembly of large space structures, long term scientific observation and manned space activities. Such cooperation should be based on substance, not appearance and not politics. And we shouldn't have to subsidize it.

4. SPACE FUNDING MUST BE BOTH ADEQUATE AND PREDICTABLE

Predictable federal funding is essential if the private sector is expected to make future commitments and long range plans. On again, off again funding, geared to a four year, presidential cycle will never encourage the private sector to make the financial commitments necessary for legitimate commercialization. Without adequate and consistent funding that transcends political fluctuations, our technical competence can wither and will have a negative impact on civil space leadership.

History has shown it to be extremely difficult to sell technical programs to the Office of Management and Budget or Congress based solely on the facts. All too often, legitimate programs must be "oversold" to Congress on the basis of optimistic estimates in order to obtain funding. This approach taxes NASA's management capability and compromises their credibility as the actual costs inevitably go way over budget.

For nearly three decades, NASA, the leading technical agency in the country, has been forced to place its priorities strongly on cost to the detriment of technical issues while annually cajoling the Congress into minimal funding. While the Federal budget has increased over 160 percent during the last thirty years, NASA's budget has decreased by more than 50 percent in real terms.

Under such strong budgetary pressures, design decisions are made which compromise both hardware capability and operational needs. Beginning with the Space Shuttle, overselling the capability and under-funding the program became standard operating procedure. The problem was magnified ten-fold with the Space Station.

A challenging technical concept, such as a permanent manned space station, cannot be turned into reality cheaply. Funding must be consistent with realistic expectations. We have the technology and the money. NASA should stop overselling programs at their inception and Congress should be realistic about the cost of achievement and leadership.

5. SPACE RESEARCH AND DEVELOPMENT IS AN INVESTMENT

America must change its attitude toward space spending. Space research and development funding is not in direct competition with entitlement programs. It as an investment which keeps the country prosperous and vital and enables us to support entitlement programs. How can we continue to afford our growing expenditures if we strangle the investment which causes revenues to grow?

Let us not become so "short term earnings minded" that we forget how long the road is that we travel. America must look beyond the next quarter's numbers to stay ahead in space.

For 30 years, America's space activities have been technology driven, a factor which continues to hinder our attempts at commercial exploitation. For real commercial success, new space based products and services must be market driven - that is, they should address unmet market needs.

The commercial pay off in space-derived new alloys, polymers, pharmaceuticals, ceramics, sensors, semi-conductor crystals and other high value materials is an elusive quest. A key issue in enlarging the market and securing a competitive position in the global marketplace, is low cost access to space.

6. ASSURED ACCESS TO SPACE THROUGH A BALANCED LAUNCH FLEET

America should balance the access to space provided by the space shuttle with programs to develop expendable launch vehicles and a new heavy lift vehicle. We have only partly recovered from the hole we dug for ourselves with the decision to phase out expendable launch vehicles in the late seventies. That decision is partially responsible for the present semi-comatose state of the space program.

Long lead times, extremely high cost, safety and reliability requirements, and national security considerations may dictate that large launch vehicle development remain, for the near term at least, an exclusive government province.

Newer and smaller entrepreneurial companies should be encouraged by the government to find a market niche. The government can help by making launch facilities available, helping to prove out technology and markets and (most importantly) developing the technology for cheaper transportation systems as rapidly as possible.

Commercialization and Entrepreneurial Investment

Companies and entrepreneurs must be attracted by capabilities and ideas that will motivate them to invest their time, energy and money. In our market driven economy, when there is a profit to be made, investment and commercial exploitation by the private sector will follow. Without a potential profit, all the government bureaucracy and offices in the world cannot force the process.

NASA should develop the technology, the heavy launch vehicles and the space infrastructure for commercial use by the private sector. If this infrastructure is well crafted, the cost of putting a pound of payload into orbit will be lowered and the genius of the American system of commercial competition will pay off as it has in aviation, telecommunications, computers, biotechnology, etc..

Private Sector Payloads

It should be more economical for American privately owned satellites and other commercial payloads to fly on U.S. government launch vehicles than to use foreign launch services. NASA should continue to fly developmental and pilot projects at bargain prices. This leaves the Government (NASA) in a position of proving up markets, lowering the cost of transportation and removing obstacles to private sector participation. It will then be up to the private sector to exploit the marketplace whenever it is cost effective to do so.

7. SPACE AND NATIONAL DEFENSE

A national space program has a legitimate and vital role to play in the future defense of this nation just as railroads and shipping did once they came into being. Our future national defense may well depend upon our capability of operating in space.

A national space policy should assure the legitimacy of DOD access to civil and commercial space programs. The DOD should be a prime customer for civil government and commercial launch services when appropriate. The "transfer" pricing for military payloads should be an attractive and cost effective alternative to any military duplication of facilities.

The overall military space program, per se, should be treated not as space policy issue but as a military/defense issue.

8. COOPERATIVE VENTURES

One characteristic of U.S. leadership in space has been its openness to international cooperation. We have shared our capability with other nations from moon rock samples to joint U.S./USSR programs such as Apollo-Soyuz and SARSAT to multi-national cooperation on Space Station. We have shared the fruits of our civil space program with over 150 nations through nearly a 1,000 agreements. There are a growing number of reasons why this program should continue.

The "Mission to Planet Earth", for example requires the close cooperation of other countries if we are to solve problems of global importance and magnitude. Similarly, missions to other planets and beyond may require resources beyond the capability of any one nation.

Cooperative space ventures with Russia, ESA, Japan and other nations should be on the bilateral agenda. Cooperation should be based on equitable contributions as well as returns. It should capitalize on the unique strengths of each partner with each partner carrying their own load – no "loss leaders"

9. STRONG LEADERSHIP AND CLEAR PRIORITIES ARE REQUIRED

Appreciating the importance of space is not equivalent to a *commitment* to America's role in space. The time is now to commit to a national space agenda.

It has been amply demonstrated that we cannot have a strong space program without some undivided attention from the Oval Office. A program of worldwide scope requires an authoritative vision - the kind that says, "This is our priority!".

A personal commitment from the President (whomever that may be) is paramount. But it requires Congress to approve it and fund it. NASA, the private sector and the Pentagon must be challenged to accomplish it. **The program must be clearly communicated to the American people who must subscribe to it.**

It will take more than the interest of the President. He must also champion the national space agenda - or the bureaucracy will swallow the program whole.

Everything possible should be done to prevent space disasters BUT we must be willing to persevere in spite of disasters and risks. We cannot let every setback result in a self flagellation of our space goals and technical capabilities. Disasters cannot be allowed to destroy the motivation of our most important assets - the people and the industrial know-how that can meet those national objectives.

CONCLUSION

In conclusion, there is a need for visionary leadership and long term space policy from the highest office of the land, supported by Congress, NASA, the Department of Defense and, most importantly, the American people.

There is a need for a national space policy which guides us well into the 21st century; a national space policy which ensures our continuation as a space technology and commercialization leader.

There is a need for entrepreneurs working with government to develop market driven products. We must look at space as an engine of economic growth, not just a place; as an investment for the next several generations and the foreseeable future.

And, we must establish space travel as a part of our national fabric, something we do as regularly and as easily as we sail the oceans and travel the highways.

This paper was begun several years ago and has incorporated the suggestions of others. RWC

Mr. HASTERT. Thank you, Mr. Cunningham. Mr. Howard.

Mr. HOWARD. Thank you. It's a pleasure to be here. There's an old joke that many of you probably know which starts when a fellow arrives in heartland America and announces, "I'm from the government. I'm here to help you." Not that funny of a joke, but you probably recognize it. I think it must be equally unsettling, though, here in Washington, when somebody arrives and says, "Hi. I'm from Hollywood. I'm here to tell you what to do." So let me just start by saying that I really only come to offer my heartfelt opinions and a few reflections. I'm not a policymaker, certainly not an astronaut. And frankly, I'm humbled by the people that I share this panel with, and also exhilarated, I need to add, by the remarks and the wisdom already offered.

So I'm not an expert. I just love this country. And I appreciate this opportunity to be able to throw in my 2 cents about our future, since it depends directly on the decisions that we made today and in the very near future. First, space has always fascinated me. And I will forever be awed by the unparalleled inspiration that went into the Apollo program and, for the record, also into the Mercury and Gemini programs.

That inspiration moved me as a boy, and it still moves me today as a man. I grew up in an America that was ambitious, courageous, unafraid of the unknown, ready to take risks in the name of curiosity, discovery, knowledge, human progress, the thrill of victory, and the preservation of the Nation's security. Two of the men who made that happen, Messieurs Aldrin and Cunningham, are here beside me today. They sat atop the *Saturn 5*—mightiest rocket ever created—and were launched into space on a pillar of fire, more than 7 million pounds of thrust.

That took courage and conviction, years of training, and hard work. It also took believing—a believing, dedicated, unafraid Nation. As many of you would imagine, I admire that achievement as much now as I did then. And this is part of the reason that I directed "Apollo 13," the movie. Before I get into a few forward-looking thoughts let me just pause and tell you why that movie, "Apollo 13," was produced by my partner, Brian Grazer, and myself.

That movie, featuring the heroism of three astronauts, tireless and ingenious NASA personnel on the ground and thousands of determined Americans, represents the best that America as a Nation can bring forth. The seeming impossibility of landing a man safely on the Moon and returning him to Earth was fresh in the American mind when *Apollo 13* was launched. *Apollo 11* and man's first steps on another celestial body—the Moon—had occurred just 9 months earlier, in July 1969.

Little did America know that *Apollo 13,* and the unforeseen explosion that rocked that little island in space, would call upon this great Nation to add impossibility to impossibility and bring human lives safely back against insurmountable odds. Every readout said that it couldn't be done, particularly in those first few hours. Every gauge spelled disaster, except the gauge of our national character. And in that single gauge America, those who knew and worked, those who supported Apollo and just prayed, found out who they were, found out who we as a Nation are.

We are a Nation that does not give up, not on a dream, not on a single human being. And in that incredible conviction, so poignantly aired by Gene Kranz's prediction that this would be our finest hour, we again took stock of who we were as a people.

Well, that was nearly 30 years ago now. And the reason I'm sitting here today before you is, I think, another crisis of sorts is upon us. Call it a slow motion *Apollo 13.*

In 1997, we must again take stock of who we are as Americans. *Apollo 11's* plaque left by Buzz Aldrin and Neil Armstrong on that same Moon that you see up there every night says we, this Nation, reached out and touched that place for all mankind. All mankind means every nation. And it means the generations to come—my kids, your kids, their kids. And that's the real point.

Today, we must see that space exploration, space development, space science, space medicine in our future both here on Earth and out there depends on the courage of our current convictions. And just as *Apollo 7, 11* and *13* defined us as a Nation, so do the decisions before Congress and this Nation today. Apollo was a magnet that in the 1960's and 1970's pulled our best and brightest kids into the study of math, the rainbow of sciences and engineering. Industry and educators, parents and policymakers were all exhilarated by the long-term goals that were set beginning with President Kennedy's pledge to reach the Moon in a decade.

And the benefits of that exhilaration are well beyond counting. The steep climb in education is why we all enjoy microwave ovens, personal computers, innumerable new medicines, electronic, avionic and basic mechanical advances. Our national security was preserved. Our commercial base and job opportunities widely expanded. Technologies which protect the environment and make for cleaner energy leaped ahead, and the sheer ripple effect propelled us forward.

The real impact runs even deeper. Exploring space and the unknown is a human quest and an American dream. Without dreams we wither. The thrill of achievement is only a memory that you and I have as a generation which lived through Apollo, because we were well served by leaders who had the long-term in mind. Now we are the leaders, in a manner of speaking.

Given the progress that we've made in space exploration since the Apollo era, historians, I believe, will hold that is was not simply curiosity, a pioneering spirit or a quest for scientific gain that carried us from the Earth to the Moon. But instead, in a political conflict, our country, motivated by patriotism and a dose of national fear, came from behind and prevailed in a space race. It's a great triumph, to be sure, but hardly the primary we would like to assign that great leap forward.

Somehow without the political threat hanging over our heads, our national appetite for exploration has been curbed. And that is a shame. Because I believe that the leaders who had the vision and the foresight to fuel our early space programs had it right. The future still belongs to those who will dare to succeed and continue succeeding in space. I'm of the mind that curiosity is not merely a human quality but is, in fact, an instinct which drives us. Human exploration of space has begun. People are going to explore the galaxies and make untold discoveries and gains in the process.

And as a patriot I hope our legacy will be that the United States of America took that lead in space and never looked back, that we grew and learned and excelled not out of fear but for the betterment of humankind. Now, that legacy is ours. We've earned it. These astronauts and thousands of others working with them have dedicated their lives to putting us into that position. The legacy will be ours if we are willing to reach for it.

To quietly take the position that given our stature at the moment we can always reassert ourselves in the area of space exploration if and when it becomes politically more pressing or necessary, that is an assumption perhaps bordering on arrogance that I hope we don't indulge in. Wouldn't it be tragic if our program somehow became an odd, ironic footnote when the story of mankind's movement into space is written, when we could have been pivotal players.

Now, you all are Members of Congress and hold the Nation's future, our future in space and the opportunity for progress and greatness in this realm in your hands. I come from an industry that dreams for a living. Together, we must, for our kids and our Nation's long-term future, think big. We have to embrace renewed discussion of a mission to Mars and a permanent human settlement on the Moon. We have to tell the Nation about the incredible discoveries that have already come out of the 83 shuttle missions. This year alone we'll get four new inoculations from a 1988 shuttle experiment and we'll save more than $1 billion in medical costs alone from a revolutionary breast cancer detection technology made possible by the shuttle program's imaging research.

There are hundreds of stories like that one. And they call on us not to give up, indeed to dig down, read that gauge again, that gauge of our national character. "Apollo 13" is just a movie. And of course, lest we forget, it's a movie of an extraordinary real life mission. And that was just one mission. But the messages that James Lovell, Jack Swigert and Fred Haise sent to us should reverberate down through the ages. And it's been almost an age since they sent it.

The message is this: When you next look up into the night sky, don't just see the past and sigh about the risk and the grandeur of what we did up there, instead, look again and see the future, see the importance of investing in, thinking and talking about, living and learning from the great place that we call space. My hope is that this hearing is the start of something really big, the start of an American reawakening about the magnificence and calling of space.

My hope is that here in Washington and out there in homes of those who see or learn about this hearing, that there will be a new resolve to see in the night sky the faces of our children, the silent call of those who would have the benefit of prideful memories and discoveries from space just as we have. What I hope these thoughts trigger, if nothing more, is a serious rethinking about the terrible and wonderful significance of space. For all mankind, we as Americans have a destiny. It is a wonderful destiny, one that I know many of you believe in, one that the men on my right have risked all for, one that I tried to capture in "Apollo 13," the movie. And now I hope that we may be able to reach together to reawaken America and to fulfill. Thank you for inviting me.

Mr. HASTERT. Thank you, Mr. Howard. At this time, Dr. Musgrave.

Mr. MUSGRAVE. Thank you very much, Mr. Chairman, for inviting me to this grand hearing in a really grand setting. I've had the privilege. And it's an incredible privilege of having been an astronaut for 30 years—space is my calling, it's what I am, it's what I do. As most of you know, I'm an incredible romantic and idealist. And so I have some ideas which may be a little divergent from others'. I am considered—I see Walt smiling—I'm considered to be organizationally and politically naive. And maybe that's to an advantage in a place like this.

But I've had the privilege of living the things that space are: exploration, discovery, brand new kinds of science that increase the knowledge of the universe and ourselves, to see and to develop some of the grandest technologies, to look down upon Earth, to communicate the vision of our home from out there, to help to instill a spirit of stewardship of our home is space, of Earth, to help to stimulate ecological issues, to learn all the time, to be exposed to the heat of the kitchen where performance is the bottom line day after day, both on a personal basis but also as an example of life long learning and education, to go out and talk to people, to talk to kids, to show them what education is all about, show them what it can do, show them how what we do in space is an entry point for their learning principles in the classroom.

I've had the extraordinary privilege of representing you all in space. There's millions of people that could have done this. Every time the door opened I put my foot in it. And I lived this thing to the greatest extent. And I gave all I could to this. But it's an incredible privilege to help humanity see what this incredible cosmos, this universe, this Earth, the planets, the stars and everything else is all about. Space flight is such a neat thing because it bridges all kinds of disciplines, the kinds of things that the telescope is showing us and all the other grand observatories, and the satellites that look at planets and the Earth.

They're not maybe quite powerful enough to yet, but if you look at Hubble images and others, we're tending to ridge that gap now between astronomy and philosophy, between cosmology and theology. Those are incredibly important things because they touch even at the elementary school level. They help to show us our universe. They help to show us as human what our place is in the universe. They help to show us—which is extraordinary important—what it means to be human.

Thanks in part to what we do in space, we are becoming global creatures, not just people of a certain town, a certain State, a certain Nation. I think it has helped to globalize the culture and humanity. As we push on into space we become solar system creatures and eventually universal creatures. We will think about, we will have a feel, we will have a geometric sense of where we are in the universe. And I think that will better our value system if we think of ourselves as a universal culture.

I think a space program, in the long-term distance, will help to guide us a as a species—a species ethic. I have a wish list, as naive as it may be, for what we ought to do—five things in the future of space, five actions which if you were to give me a wish list what would I like to see happen. No. 1 is low cost access to space. We've been into space for about 40 years now, and we have made no headway at all in terms of reducing the costs of space flight. I've got to put that as the No. 1 priority. All of the fantastic potential and the dreams which Buzz so eloquently set forth, they can only happen if we reduce the cost.

We can't launch a bunch of telescopes and we can't get inter-privatization, commercialization, studies of the Earth. Cost of space flight is the basic common denominator which is going to allow everything else to happen. It will allow space, in ways, to pay for itself. It will make all those things which Buzz set forth as potentials for future space flight. They can only happen if you reduce the cost of space flight.

I've never worked in Washington. I've never, you know, been at that level. I have been in the trenches for 30 years. And so I'm not sure how to implement this. But if I was where you were I would establish the mandate for lowering the cost of space flight as the No. 1 priority of space. At some level I would force NASA and DOD, the contractors, the industry and the commercial and private sectors who want to use space and who are driven by the market, to get together—and I would give them a mandate. And there is only one bottom line. And that is: lower the cost of space flight. I would not specify to them that it has to be a single stage or a two-stage or a multi-stage.

I would leave the best thinkers in the business to come up with the right solution, the most simple and elegant technology to get that job done. Most of the conversation we've been talking about here today is from the 60's, from what you call the golden era of space. There's a reason for that—is that we had an extraordinary hard line task to do. And that is, go to the Moon. Going to the Moon defined the way we did business.

We had to get there in 8 years. And we were told to do that. And we went and we did that. In 8 years we launched four programs—Mercury, Gemini, Apollo—and we were well on our way to a hugely successful space station program, and we did that within a decade. Because we had a mandate to go do it. And we only had one line. We had one statement at the bottom line: to the Moon and back in this decade.

That harnessed our energies. It focused our efforts. That bottom line built the entire structure. It built our organization and the way we did business. I think if we have a single hard line and you made us go do it in the near term, NASA does have some very, very high tech ideas, technological development, very futuristic ideas. But the technological challenge is absolutely immense. It is very, very speculative. And we may get into a very, very long-term technological development process and we may find out that we can't get there that way. And then we will band-aid that and back off into something else.

I would like to see a hard bottom line that says, everyone go out there: low cost to space in roughly about 5 years, not 15 and not 20. And it's totally reasonable. Kennedy says, go to the Moon. The same year we launched a Saturn. The programs back then were 2 or 3 year programs. And I'll get to that a little later. I think that is the highest priority we have—is reducing the cost of space flight.

No. 2: I think we ought to examine the way we do business. I think we need to confess to ourselves what our victories are and what our failures are, what we're good at and what we're not so good at. I think we need to be extraordinary hard-nosed realists about how we are really doing. A space station should not take 20 years. It took 10 years to launch four programs in the 1960's. If we want to do a space station in 5 years we need to get the will and the courage, and we simply need a deadline; and put it on paper and go do it.

I think to do all the things here that Buzz, that Walt and that Ron put forward, I think the bottom line says just simply get on with it. Get on with low cost to space. Get on with the station. And do it. When you all gave us the privilege such as, go to a space station, and you say you're going to support it and you let us embark on that initiative, we need to go do it and we need to have hardware in orbit within 4 or 5 years.

It's a perfectly reasonable thing to do. It's only a matter of setting ourselves a hard standard and living with it. And I think the approach—even though I won't spend that many details on it—the approach ought to be: come up with a simple, elegant, beautiful flying machine. Start there. Do not expect the design to evolve from 20,000 users. Come up with the best possible beautiful machine within 1 year, as a concept. Spend 1 other year modifying that to meet the major users.

Spend 1 other year to get to a critical design. And then next year, 4 years later, start budget hardware. Just like we marched in the old days, there's no reason why you can't flow the decisions. You start with critical decisions that cascade into other places. You attach names and dates and you start marching around that flow chart that's around the room. We simply get on with it. That was No. 2.

No. 3, I would like to see a start embarking on what the human program will be beyond the space shuttle. I think we need to start on that now. I would like to see us have simple, elegant human machines like a reusable capsule, which is totally forgiving. It is low-tech. We already have the technology to do that. It is totally capable. And it has high margins in terms of reserves and other kinds of capabilities. I'm not saying that is the way to go. But I'd say we should not forget some of that grand technology.

We need to include that in our thinking about what we ought to be doing, because the technology is great. The capability is there. And it's cheap. And we know how to do that today. We ought to include that kind of thing in our thinking.

No. 4: I would like to see—evaluate our priorities in terms of how many resources we are spending to reach the quest—the far our things which Buzz and Walt alluded to—and how many resources are in Earth orbital programs. I would like to see human programs which do not devour our entire space effort. We need human programs that we fly humans to when we need humans in space. But we don't have to fly humans when we don't need to fly humans. And a reusable capsule is one way to approach that. A specific payload module could be another part of the thing. You fly a specific payload module. That's more details than we need to get into here.

But I would like to see us pursue—the way to guarantee human space flight is to have a human space program that does not devour all of our resources. Another point is our collaboration which Walt mentioned. Our collaboration with partners is essential. We do need to collaborate. I love the partners that we have. But we need to do intelligent, creative partnering. We need to look at our strengths and our weaknesses, and we need to optimize how we collaborate and how we do partnership.

We do not want to go into massive programs and try to weld cultures—how to weld different cultures, weld different technologies and weld ourselves together—it does not serve either of us or serve space flight. Partnering needs to be very creative and very intelligent. And it needs to be very selective.

My last point is, is that there is huge grass roots support out there. The Congress has supported space flight incredibly for the last 35 or 40 years. We thank you for all that support. It has been absolutely loads of support. With all I do out there with the media but also out there hands on with the kids—yesterday I met with 500 high risk underprivileged kids. And I told them about space. I mixed it up with them. They do not consider themselves apart from the space program—or the support of them. The safety net from them is in competition with space because they want to do Buzz's dreams.

They want to be part of that. They don't want that to go away. That is their hope. That is their future. It's their science. It's their technology. There is huge grass roots people support for space. But such as to not let them down, I think the key thing that we are doing in the space industry is we have got to get on with it. We've got to simply do it. It doesn't mean it is any less in terms of its capabilities or its qualities. We've simply got to, when we get the initiative and the resource to do something, we've got to get on with it. Thank you.

Mr. HASTERT. Thank you very much. And thank all our panelists. Very enlightening. I think some great vision for us to focus on. First I would like to allow 5 minutes to Mr. Souder, from Indiana, to ask questions.

Mr. SOUDER. First I just wanted to clarify for the record with Mr. Aldrin. You weren't claiming to be the role model for Buzz Lightyear, were you?

Mr. ALDRIN. I was told they surveyed names and they looked on a typical one, a catchy one. And I'm happy about the choice.

Mr. SOUDER. They picked Buzz, right? And Dr. Musgrave, to start with yours because it related to some of the others, are you suggesting that currently we have too many missions regarding NASA and can't do any of them with enough funds to back it up, given the limited budget?

Mr. MUSGRAVE. I don't work in Washington, sir, and I don't work the budget. And you know, I'm coming from here looking up. I do not think it's a matter of resources. We said this station is going to cost $8.4 million back in 1984. By next year—1998—we will have spent $20 billion in 14 years. And there is not a single nut or a screw in orbit. If we simply get on with things in a logical fashion in which we set hard decisions, dates on the decisions and attach names to those decisions and make it happen, that is the answer.

Mr. SOUDER. One of the problems—and at least of those of you who have been in space—Mr. Aldrin started out by saying, had this happened or this happened or this happened you would still be on the Moon. One of the problems that we have when we get into defense contracting—for example ITT Aerospace is in my district with a number of plants. They have to make radios that actually outlast their operators. In other words, they put so much into making it perfect because of what Mr. Cunningham—and I hesitate to say Mr. Cunningham; by Mr. Cunningham, I mean this Mr. Cunningham—that you said we're risk averse. And that's the cost of a lot of these products.

In other words, people look at it and say, well, we could do that for a lot less. We could build a hammer for less than $700. But you can't custom make a hammer that survives in all sorts of temperatures and all sorts of things with no risk. What tradeoff, as people who have been out there in space, would you be willing to make in the safety versus the risk if that achieves some of your low cost objectives?

Mr. CUNNINGHAM. Well, I believe that, as we look at space——

Mr. HASTERT. Would you please? It's kind of noisy. If you'd pull that up closer I think it would be helpful.

Mr. CUNNINGHAM. OK. As we look at space—and I'll restrict my remarks to that—we need to, all of us, acknowledge that there are gains to be made through the utilization of space—No. 1. No. 2: there always will be risks in space flight. It's the most—probably the most dangerous environment that man has ever gone into. So we know there is always going to be risks there.

These risks—and we're not going to be able to reduce them to zero—but at some level they can be acceptable relative to the potential gains from it. And we ought to reduce those inherent risks as much as we can, and then get on with the job, as Story says. Now, I don't believe it can be zero. But the problem that I was addressing is that in our society today, everybody is being raised to think that no risk is acceptable. So how can you come to an intelligent assessment of what is acceptable. I mean, no risk seems to be the rule of the day.

Now, we also have things to learn about risk. And we have learned over the years—I don't think I'm the only one up here that would say—if we look at the Russian space program, they've accomplished a tremendous amount with equipment that I would certainly consider much less sophisticated than we have. I don't endorse all of the things that they do. And I think there are some problems. But we have learned along the way that you don't have to have so many belts and suspenders as we have. We're seeing it right now in the Mir Space Station. And you can still get by and you can still have some safety.

Mr. SOUDER. That's especially meaningful given you were backup on *Apollo 1.* And certainly the *Challenger* and the other things that occurred have, in a sense, scared the American people. And it's so visible when there is a failure that there is a fear that the budget will evaporate. It's on national and international TV day after day when there's an accident.

Mr. CUNNINGHAM. I would like to say something about that. Because as I think back on it. The risks always seem to be bigger to those outside of the program. I don't recall—I think it was about 3 weeks after the *Apollo 1* fire, that our backup crew was promoted to the prime crew for the next mission. And other than a reasonable engineering judgment about having to fix a lot of things—and we didn't even know what they were—I don't recall ever having concern that there was going to be some untoward risk. I knew that we were going to do the best job that we could. It was part of what went with the job. And I don't remember ever spending 1 60-second minute stopping and thinking about it.

But today every time something happens there is that concern. And for example, after the *Challenger* accident, I personally was concerned that Congress would find that too discouraging even to keep funding some of these programs. And we shouldn't. The very price of progress is risk. And I don't want to seem callous about human life. But lives are given up for progress every day.

Mr. HASTERT. Some of our members would like to ask another round of questions. And we'll do that. Mr. Portman from Ohio.

Mr. PORTMAN. Thank you, Mr. Chairman. And thanks for the inspirational message from all of you. It was great to hear from each of you as to your perspectives. And I'm getting a little pumped up about the space program here. I've traditionally been more of a deficit hawk on all programs including the space station as an example, Dr. Musgrave. And I've not been able to support that for some of the reasons that you've outlined. But I probably come here as a lot of Americans, having enjoyed Mr. Howard's movie immensely, and having grown up watching Buzz Aldrin and my constituent, Neil Armstrong—and want to see it done in a way that's cost effective and continues to be inspirational, particularly to our younger generation.

Dr. Weldon has the Kennedy Space Center as his constituent. I have Neil Armstrong as my constituent. And I really appreciate it, Buzz, your talk with me earlier and your remarks today. My question to the whole panel—and I will direct it to everyone, but sort of building on what Dr. Musgrave was talking about—is how can we, in an era of balanced budgets—I remember in 1969, the space program really got underway after the 1961 inspiration with regard to *Apollo 11,* we had a balanced budget. I think we actually had a little surplus that year. And now we're $3 trillion in debt at last count and running annual deficits.

On the cost-effective side of it, I couldn't agree with you more in terms of really saving the program. In other words, if it's not cost effective I don't think we will have the kind of grass roots support that you're talking about. Do you have some specific priorities, Mr. Cunningham, Mr. Aldrin, Ron Howard, that you think are the top priorities that we ought to focus on? You talked about some about the various programs and gave us a nice laundry list. How would you prioritize those?

Mr. ALDRIN. I think reusability in our launch systems is primary. And I think affordability and reasonableness. We designed, finally, a shuttle system after several compromises. And it didn't quite live up to our expectations. The space station, as Story pointed out, was going to cost a lot less, going to be completed sooner, and it didn't live quite up to our expectations. And the national aerospace plane is no longer really a project. I think we should have a little caution about how we chart the course and what we expect out of the next commitment that we make. We should make sure that it's within our grasp. And most toward—I just don't think the American people are going to want to see us not quite make our objective the next time.

Mr. PORTMAN. Was one of the problems—and I know there are lots of issues. I don't want to get into the space station too much. But in a general sense, in terms of cost effectiveness—Mr. Cunningham talked about international partners and the degree to which we should be subsidizing them. I think you said that we need to set up a deal that's tough in advance, and not subsidize our international partners.

And some of you have touched on the issue, I think, indirectly, of the politics here. In other words, with the space station here, you might have different constituencies out there in different Members' districts—that Mr. Cunningham, in your comments you were saying that shouldn't be a factor, we should do this on the basis of the merits. And Dr. Musgrave was saying let's get on with it and do the right thing with our private sector partners. Is that part of the problem generally?

Mr. CUNNINGHAM. Well, I think over the years—I can recall back in the days of Apollo, one of the things that they were looking for was to try to make that there was some contractor in every state of union, because it could grab the interest of the Congressman. I believe that that is—while that may be politically the right thing to do—I don't believe that that is economically or even on principle the right thing to do.

You asked a question about the budget and how do we do these things. If you look back over the budget—and in my proposed policy I make the comment that the Federal budget has gone up by 165 percent in the last 30 years and the NASA budget has gone down by 50 percent in terms of real dollars. So you're tying to get more and more for less and less, is one of the things. Second, if you take a look at the budget for the last 30 years spread out here broken down by national defense, general science, mandatory payments, interest and then other domestic programs, it's pretty simple to see that the only monetonically increasing function is other domestic programs over the last 30 years, being paid for out of the hides of the rest of categories, and most notably national defense, which—I object to that, as well. And the general science in space category has gone down until you almost can't see it on this particular chart.

Another specific suggestion I might make is that when you find that through a recalculation that the tax revenues are going to go up over the next 5 years be $225 billion, that you contribute some of that, you find some ways of using that for something other than just additional entitlement programs.

Mr. PORTMAN. I see my time is up. Let me just make one final comment. Maybe Dr. Musgrave or Mr. Howard could respond to.

You started, Dr. Musgrave, saying that you are naive about politics and government.

Mr. MUSGRAVE. Yes.

Mr. PORTMAN. Let me suggest this morning that you may be least naive of all of us by focusing, again, on the cost effective issue here as your first priority. And then really down the list I think all of your priorities were on target in terms of the political reality that we face. Do you have any comments on my earlier question?

Mr. MUSGRAVE. No, I don't, sir. I think that will let space open up. That will let space get privatized. And that will let the commercial sector—that will let it become market driven. I don't know exactly what the forces are. In terms of launch capability, the United States is only launching 25 percent of commercial satellites. We used to do 100 percent. And I don't know exactly what is going on. Right know there are satellites waiting to be launched and there is no launch vehicle to get on this.

It came out in the space Congress in Cocoa Beach last week. This satellite is waiting to go and there is no launch vehicle anywhere in the world to do that job. I do not know why the market has not driven the large aerospace companies to come up with on their own—with a launch vehicle. And since that has not happened, I think we, the government, needs to take the lead. Once we have those vehicles, we can hand it over to industry.

Mr. HOWARD. If I could add, just to kind of again—being kind of a simplistic point—but, you know, coming from a business that is always trying to sell sort of simple ideas that people can grasp and decide to embrace—a movie idea, a television show and so forth—one of the things that we talked about a lot when we were making "Apollo 13" and talking about the space program and our love of it and its hope for the future and so forth, one of the things that was discussed was that in sort of a public relations tactic and strategy it might be valuable to actually come up with two lists: one, as I mentioned in my comments, sort of a list of things that we really have gained. And actually try to put a number on that, try to come up with some calculation that says, this has generated X-number of dollars for our economy. This is what we estimate.

Here's probably what it cost to generate the technology. And then, second would be to say, here are our projects—and whether it's the station, whether it's going to Mars, whatever that objective—as you're saying, the objective that wants to be set and established—to actually come up with a list of three or four key objectives, knowing that sort of broad science is a part of it, and there are going to be discoveries that nobody can quite calculate. But come up with a handful of objectives and project the same kind of numbers to them, so you're actually saying to the people, here's what it has cost, but look. If it's actually like what we were able to generate out of the Apollo era with the technologies and the shuttle era and so forth, look how much we stand to gain on a military level, on a security level, on a business level, in terms of living, lifestyle.

Mr. PORTMAN. Sounds like the boys in Washington, doesn't he? It's got a pretty good——

Mr. MUSGRAVE. We've got to continue to touch people too. Not just their intellect and the numbers, but you're got to touch them right down here. And not just in the visual. And space flight does that. Images and the kind of stuff. And shedding light on people's place in the universe.

Mr. PORTMAN. And you all have done that this morning very effectively.

Mr. HASTERT. Thank the gentleman from Ohio. And I know you have another engagement and you have to leave us. But thanks for being with us this morning. At this time I'd like to turn to Dr. Weldon, from Florida.

Mr. WELDON. I thank the chairman. And I, too, also want to thank all of the panelists. This has really been very enjoyable for me. And I could really sit here all day and talk space with you. Let me begin, though, by asking Mr. Howard—you know, I saw "Apollo 13." It was a great movie. I took my daughter. And needless to say it was a big hit on the space coast of Florida, where I hail from. But I don't follow the trade press when it comes to Hollywood movies. Was that movie a big hit or a medium hit? What would you say it was overall? You don't have to give me numbers or anything like that.

Mr. HOWARD. It was a huge hit.

Mr. WELDON. A huge hit.

Mr. HOWARD. World-wide.

Mr. WELDON. World-wide? Is that right?

Mr. HOWARD. My most successful film to date by double—double any film in terms of just ticket sales and revenues.

Mr. WELDON. Well, that's fascinating to hear that. So it was very popular in Asia and Europe and other places?

Mr. HOWARD. Very.

Mr. WELDON. Because I remember during that crisis of *Apollo 13* how they were actually praying for the astronauts in the Vatican. And I think the Pope had the Italian people praying. So I could readily see how it could have a huge worldwide appeal.

Mr. HOWARD. There's also—you know, we did a lot of international publicity for it. And you know, while there might be a degree of cynicism always expressed about America from journalists abroad, when it came to the subject of the space program, they were absolutely fascinated and continued to be—the vast majority of journalists that I spoke to—inspired by it. And you know, I think their sense is that it's one of the great accomplishments that America has offered. And you know, they're fairly dubious about America in other areas and other ways. But here's one that pretty much everybody seems to agree was a great, great accomplishment.

Mr. WELDON. Did you get any feedback in terms of the impact it had on children? You know, if we're going to talk about man's future in space, we have to talk about kids and education. Because if we are going to go to Mars and we are going to go onto other solar systems, it's going to be the children. And I know my daughter very much enjoyed the movie. And she's still in grade school.

Mr. HOWARD. Well, you know, I was very pleasantly surprised by the way children responded to the movie. And I didn't necessarily expect that. I initially went in to the film thinking it was more or less a historic drama, a kind of a techno-thriller. And I'd always been a great proponent of the space program and followed it. But I didn't really understand and still don't pretend to, honestly—but

I didn't really understand that monumental endeavor that the space program represents, the years and years of diligent, focused work.

And if I could add one thing about the astronauts that I met and actually worked with in trying to understand the mission and research the mission, all men well into their 60's as I was working with them. And the comment that we all had was that they shared one thing: an unbelievable passion and intellectual endurance. I mean, when you sat down and started talking about these missions, we could go on until 2 or 3 a.m., and the 30-year old guys were burned out and the 65-year old guys were ready to talk some more and understand and explain.

And there's something very stimulating about that. And I think that I tried to get that feeling into the movie. And to answer your question, I was very pleasantly surprised by the way younger audience members responded to it, not just in terms of box office, but in terms of the letters, the way the film has been used to teach not only the history of the space program but also physics and basic science in schools. So I think, for that moment, I think the film helped stimulate people's imaginations.

Mr. WELDON. Well, I'm glad to hear you talk about that passion issue. Because I know I see a lot of that in my district. A lot of those men and women who worked in the space program, they're still excited, they still want to go back to Mars. In closing, I'd just like to open it up to the other panelists. Can we really put a dollar value on these kinds of things? You know, when we start talking about going back to the Moon and going to Mars, I'm very well versed as a physician with the medical spinoffs and the impact that that's had on improving people's health and the material science breakthroughs that have occurred. But just in the impact that it has had in the hearts and the minds and the passions of people, and particularly our young people, is it right for men and women in Congress to always be putting a dollar value on this program? I think not. I think it's our future.

Mr. CUNNINGHAM. I think you can put a dollar value on many of things such as the statistic that Ron has already mentioned. But whatever you come up with in a dollar value it's going to be greatly undervalued because you're not going to be able to appraise what it does for the indomitable human spirit, what it does for education.

I'm involved with the organization called Space America Foundation. And we are preparing lesson plans and trying to get a series of—for science and chemistry and a variety of courses in the texts of schools that uses about 30 video tapes from the space program. The lesson ties in physics, mathematics and you name it. And there's great enthusiasm from both the students and the teachers from being able to use examples from the space program in their lesson plans for their teaching. So, it's a tremendous motivation.

Mr. MUSGRAVE. If we just look beyond that curtain there you'll see what's going on. It's right there.

Mr. ALDRIN. You talk about trying to get a monetary value. People can estimate what the Apollo program cost us. But what I've learned in the last 27 years is that when I speak to people sooner or later there's almost a compulsion for them to tell me where they were when Neil and I walked on the Moon. And I'm trying to understand what that means. To me it means that they value not the rocks that they brought back or what they said, but what happened in their lives. Something happened that caused them to remember in a very positive, a very satisfying way, a particular moment. And I just stimulate the recalling of that. And that's valuable to them. How do you put a dollar sign on that when you multiply it by millions of people around the world. I look forward to the year——

Mr. WELDON. Do you want me to tell you where I was?

Mr. ALDRIN. I'm trying to remember where everyone was, Congressman. When I look at the year 2030 I think there are going to be people alive that are going to cherish the moment and the sense of value that they experienced in their lives by seeing a nation step up and make a commitment shortly after the turn of the century to establish a foot-hold on Mars and see that grow.

In 2030 they're going to say, this started out with five people, seven, and it's now grown. We have 25 people thriving on the surface of Mars. And this is being supported internationally. Think of all the things that will come from the nations of the world dedicating themselves to the survival and the improvement of that small growing community. If the asteroid comes and blows us all up, that may be the future of humanity. And don't think that's—sooner or later a responsible society needs to guarantee their own survival. And survival, I think, takes an advanced, stimulating spirit of humanity. And that's what the space program is all about. It's not the balance sheet, what we get out of it in terms of dollars.

Mr. WELDON. Thank you.

Mr. HASTERT. I thank the gentleman from Florida. We'll come back to some more questions from this panel. First of all, Dr. Aldrin, a couple of things. You talked about the—and let me just say that this is an interesting hearing we're having. Usually we're looking into the problems in government and somebody breaking the laws and where dollars are misspent and all these types of things. In a sense, you bring us today some vision that we don't usually get to look at and luxuriate. And really, for a backdrop for where we go in the future as politicians and Members of Congress and just the nature of our work, we don't do the vision thing enough to use as a backdrop of where we've been, and what steps we need to take to get there.

So, I think this is a very, very good exercise for us. And I really appreciate your time in helping us do this. Dr. Aldrin, you talked about the Star Booster approach based on the use of existing hardware. Please tell us about that briefly.

Mr. ALDRIN. I believe we need a rugged, resilient approach to access to space, to bringing down the cost of that. And I think that's best done by a multi-stage vehicle and using something that exists and then making it reusable. The Boeing Co. has recently embarked on a sea launch program. And they've chosen for their rocket not an American rocket, not a French rocket, but a Russian rocket—Ukrainian rocket, really.

It's in, I think, the first stage, with an airplane wrapped around it called a Star Booster—has multiple applications—first stage with a reusable upper stage or a capsule on top of engines and tanks. As Story mentioned, we can put payloads on top of that. Then that can be strapped three or four of them around a core stage, like the external tank on the shuttle, and now we've got the hotel in space for the tourists to go to. And that hotel in space needs the same booster that it takes to go to the Moon and Mars. I think the public support will be behind the reusable spacecraft and rocket systems that will help them get access to space.

Mr. HASTERT. You peaked my interest when you were talking about solar energy. I happen to sit on another committee on energy and commerce issues. One of the things that we're talking about—again, in the 60's and 70's we were talking about nuclear energy and it was going to be for the future and electricity was going to be too cheap to meter. And today, we'll probably not build another nuclear reactor in this country. You talk about solar energy. How does that work and how do we bring it to Earth?

Mr. ALDRIN. I think in later panels—I know for a fact that we have experts who can tell you how to harness the energy of the Sun and solar in a better way than on the surface of the Earth. And then solar panels in space direct energy to where it's needed on the Earth. Some of the economies of beaming this energy from the distance of the Moon using lunar resources to do this prove to be a superior economic approach to doing this.

Mr. HASTERT. Dr. Musgrave, you talk about why we haven't been able to step up to the plate, so to speak, and take the risk and why the private sector hasn't done that. And certainly somebody from government—I've come out of the private sector originally—shouldn't be pointing fingers at the private sector, but I would suggest that probably as long as the Federal Government was going to take the economic risk and build the equipment and do the research and be involved—unfortunately we get bogged down in the bureaucracy of the system where the private sector doesn't. Also, it costs us much more to do it. But as long as we're willing to do it, the private sector is not going to take that risk. You want to talk about that a little bit just in your viewpoint?

Mr. MUSGRAVE. You're probably right, sir. But since, in 35 or 40 years it hasn't happened and our entire space program and infrastructure depends upon that I think that we ought to do it.

Mr. HASTERT. That the government ought to do it?

Mr. MUSGRAVE. Yes, sir.

Mr. CUNNINGHAM. If I may answer that a little bit?

Mr. HASTERT. Sure.

Mr. CUNNINGHAM. I'm a venture capitalist. It's what I do for a living. Invest in early stage companies getting started. I can assure you that when there is a profit to be made in space that private enterprise will certainly by willing to come in and make a profit. It can't be forced. It can't be able to look like it's a phony deal and there really is no profit in it. So, I take a slightly different perspective that maybe the only way that it's ever going to be able to get private enterprise involved in it is to have the infrastructure established by governmental bodies in one place or another.

Whether that's the cost of transportation, which is the key to making a profit in space, or whether it's establishing power systems in orbit that you then can plug into if you send your own satellites up and the like. But I don't believe that private enterprise—

and I see all these deals that come down the pike—are not going to do it in space until there is a profit to be made in space.

Mr. HASTERT. Mr. Howard, I just want to say I also enjoyed your movie. I happened to watch it at 40,000 feet halfway across the Pacific. It gave me a little bit of consternation from time to time. I wondered how do you get down from there? But let me ask you—and, again, from somebody who is out of the government sector—but when you make a movie you have a goal and you have so much money to make it, and you have a time line. And the longer that time line stretches out, most of our people here who have been very much involved in space say, just do it. Is that the attitude that you kind of take with a movie that if you stretched it out too long you can't afford to do it?

Mr. HOWARD. Well, yes. You know, it's a much different situation because the film distributor is making an investment in a specific project. But that film distributor has a need. And that need is movies or television shows.

Mr. HASTERT. To have a product.

Mr. HOWARD. And so the real question is going to be not so much will they have the movie. Certainly they're going to decide on movies. How much do they want to spend on each individual one? And will that film return? And for that reason there is always—that's why it's such an impossible business to predict. And it's so maddening for people who get into it as a business, even though companies grown and make profits.

Movie making—everybody sort of imagines that it's completely out of control—egomaniacs running around in this totally undisciplined fashion. But the fact of the matter is, that if any movie project goes more than about 10 percent over its budget, everybody is in trouble—the director, the producer—everybody is humiliated. It's a bad mark. And so, they've somehow—movie people have been able to learn how to work toward a number. And that's often what it boils down to.

They make an estimate, they agree, and then there's a kind of a fluidity. There's a kind of a give and take as they go, working toward the objective, keeping the number in mind. And I think that's how filmmakers are expected to try to live up to the targeted number. Sometimes it doesn't work at all. But generally, as I said, there's usually about a 5 to 10 percent differential.

Mr. HASTERT. Well, my time has expired. But the three gentleman previous who have spoken basically said, as I understand it, that one of our problems is that we are risk averse in our country. And part of that is a political problem that we have, as well. But as Mr. Aldrin said, that we never have probably explored this country or done the things that we need to do if we were going to worry about risk all the time. And there is a certain aspect of doing it, saying that this is the job to do, here is our task, move forward and get it done, and to do it within a certain limit on dollars or expenditures. I hope that we can take that philosophy and start to move that forward. I think that's a very positive thing to come out of this hearing. Mr. Souder.

Mr. SOUDER. One of the things that all of you are really addressing and that we face is how to motivate people. Part of our job as leaders is to lead and part is to be representative of where the people are. And if we get too far ahead of the people we're no longer here. And this is a mixed bag in the general public. It's fine to say, oh, we like the shuttle, but don't take my Medicare check, I want my road, don't raise my taxes. And so we have to also catch their imagination. And I wanted to start with Mr. Howard but then ripple this through, because each of you touched on this.

You're in a very unique position, because the baby boomers grew up watching you grow up as Opie, Richie Cunningham. Then you made the transition into making movies that impact and reflect a lot of our lives. You're in a very unique position to influence the biggest groups of people in the society. And I commend you for having done so in a way that motivates.

Mr. HOWARD. Thank you.

Mr. SOUDER. But as you go into that, you touched on something that Mr. Cunningham alluded to. And I wanted to mix these two points. One is, as clearly science can motivate to a point, but it's doubtful—my dad left me a Buck Rogers gun and we had the Jetsons, but the truth is that in spite of all the rhetoric we wouldn't have had a space program without the Sputnik and without concern for the military questions, that while movies like "Apollo 13" were moving and had a big audience, Steven Spielberg has tapped into another thing, and with the adventure movies, "Star Wars," when you look at the sales of "Independence Day," those were really militaristic versions of how outer space works.

And that captures the people's minds. And looking at what motivates people, well known consultant, Dick Morris, says it's love/hate or love/anger and hope and fear. Part of this is hope, part of it's fear and how to capture this. And you said in your statement the importance of the hope and the vision. But there also has to be, this is important for us as a Nation. And clearly, when you make movies, you had adventure in your movie, the suspense of whether somebody was going to die. I mean, it was a human story in addition to capturing the vision of space.

Mr. HOWARD. Right.

Mr. SOUDER. We also—and one fundamental thing here is that while science is important we do some things that may or may not be politically important because of the future of the country, but Mr. Aldrin was saying and the others—Dr. Musgrave, and Mr. Cunningham said to a degree too is—the core question is, is it space that catches people's imagination or is it humans in space?

Is it the human aspect that when they think of a colony on Mars, a battle in space, what does this mean to us? Are we going to travel out there? Is it very—are we so oriented ourselves that that has to be—those two things have to be the key parts with science being something we do because it's important and we see the benefits? Could you address that some as somebody who is especially motivating people—because if you don't motivate them you don't get them there——

Mr. HOWARD. Right.

Mr. SOUDER. And then each of you kind of touch on that. Because you've all been addressing this. How do we capture the human imagination, not just in kind of theory of what people should want to do. But how do you actually move them to say, yes, we'll spend more money on this and we'll sacrifice a little to do it?

Mr. HOWARD. Well, you know, there are probably a few things that leap to mind. One is, since we're not involved in a sort of a veiled military conflict or the fear of one at the moment, there is a kind of, sort of like the spirit of accomplishment. And I think we can apply a sort of a nationalism to that, although I agree with Dr. Musgrave that one of the things that I love about the exploration of space is this idea that it pulls us all together. But at the moment, I think, in the way that we love to see Americans win gold medals. I think that we're, as a Nation, very proud of what we've accomplished and that there is a very legitimate reason to fear that somehow we will not sustain this lead in this area.

This would be tragic. I don't think that is anything that very many American want to think about or face. I've had conversations with astronauts talking about how they've had more inquiries from other governments about ideas that they've put forth than the American government. However, I'm not an expert and I don't know whether these individuals' ideas really had merit or not.

But the fact of the matter is that we are not the only ones looking into the possibilities of space exploration. Yes, we're still in the lead. And I think that is a reason to fear, to have some fear. And while there's not a direct opponent, that the idea of just sort of kicking back and saying, we've done that, is poor thinking. And I think that can be dramatized. And that was also why I was making the point earlier about everything that's been achieved and the possibilities for achievement.

If there is a superior energy resource that can be achieved, then as a Nation wouldn't we like to be the ones that present that to the rest of the world? Wouldn't we like to be in the lead? I think that there are ways of presenting it as very important to our lives in the future. Of course, there is always this spirit of adventure and the pioneerism. We're a Nation of pioneers; everybody relates to that.

Mr. SOUDER. I would like to hear the other three panelists address this too. If you could expand in addition to national pride, is there a reason to fear that if somebody got there first they could control us or other nations if they had the wrong motives or control energy sources and not be necessarily as willing to share with mankind?

Mr. MUSGRAVE. I might go back to the question that went to Ron. The kinds of science that people can really appreciate are the data that comes to them in a direct, perceptual sense. It's hard for them to understand maybe an equation when they're not experts in that discipline. But when you can present something which is directly perceptual such as an aesthetic visual image of astronomical data or of looking at Earth or other things, that really does work. I have found the human experience, they do vicariously want to go into space.

We are just representative of them and have that privilege. But if we penetrate the head and the heart they are far more appreciative in terms of what you give them as opposed to a list of what you did and a chronological history of events that occurred if you give them what is going on in your head, your experience of the work that you are doing, your perception of how your body is doing in this environment that it was not designed to be in, then that touches. If you present it and let them live space through a character the same way Ron's movie does or the Spielberg ones, it is always through some characters that the drama takes place. So to let the public lie that through a personality, I think, is important.

Mr. CUNNINGHAM. I've always—I think almost always found that when I'm abroad there seems to be more grass roots enthusiasm about space and about what we're doing. Some of it you might put in the—probably the nature of envy in the sense that they don't have the same level. Maybe they would get more blasé if they did; but I doubt it. I think that's kind of a characteristic of the Americans. We tend to get this tremendous accomplishment. Then we start taking it for granted and we just get blasé about it saying, "I already did that."

I've also always been confused by the fact that for the last 20 years at least I've listened to the debate when they start talking about the space budget—usually it's a fight every year—and Congressman say, well, I don't see the support in my district, or it doesn't seem to be a gut level issue. And yet in my involvement with that same public out there, I always feel—it's at least a 90 percent positive response even when I discount it for the fact that they're talking to an astronaut and would like to encourage me. There always seems to be a gap between what you gentleman may be getting from your district and what I would see if I was out there in that district.

And I sometimes wonder when we look at these priorities—because we have those tradeoffs. I'm at the age when I'm concerned about Medicare now, too, myself. But there has to be some sacrifices someplace. But is it the public's priorities or sometimes could it not be the politicians defining the public's priorities by making appeals to the electorate in certain areas. There is no question that when it comes to pocket book issues it's a more effective appeal to somebody if you're going to give him something than it is if he sees that you're spending something for it.

Going back to John F. Kennedy's statement. He wasn't reflecting any grass roots push to announce a program like this. I mean, he was stepping out in front. And I don't think it's ever going to be the grass that's going to demand one of these kinds of programs.

Mr. SOUDER. Can I interrupt you just a second?

Mr. CUNNINGHAM. Yes.

Mr. SOUDER. The fact is, though, I remember a bomb shelter in our basement when we were putting things away and we were fearful of the Russians getting up there. I think there was more grass roots to do something that you're—I understand, maybe not in the way he was. But there was a grass roots support that was driving from a defense standpoint.

Mr. CUNNINGHAM. Also there's also no question that there really was a space race. And that was essentially a battle in the cold war—is what it really boiled down to.

Mr. SOUDER. Yes.

Mr. CUNNINGHAM. But when I'm talking about going to putting a man on the Moon, that went beyond just defending against rockets in space.

Mr. SOUDER. Yes.

Mr. CUNNINGHAM. I think it takes somebody to verbalize this vision. It gets accepted by the public if it appeals to their heart. Something in here has to grab you that makes you excited about it.

Mr. ALDRIN. I think if I understand you, the public participation and identification and association with what we're doing in space is essential. Look at the popularity—the world's most popular museum is where we are right now. The popularity of space camps, of Challenger centers—the young people and adults want to see a hands-on participation, when it's, in the next several years, someone having an experience for a limited time to control the movement of a robot on the surface of Mars—sure, it's a robot, it's a machine—but there is a person and he's looking forward to his involvement in doing that. Vicariously, through virtual reality, I think people want to get involved and be a participant in this. That's why they come to all these museums. I think that that's why they want to participate—maybe it's vicariously—in cheering the winner of a random drawing of shares for a ride to go into space or they're taking a chance of some sort and then getting a little bit of a surprise. I think it's that kind of participation and involvement which is absolutely essential to broaden and give concreteness to this thin veneer of support for adventure that has often weighed against the press of the immediate demand. I think we need that continued involvement.

Mr. SOUDER. Thanks for your efforts here today and also just across the country in helping boost interest.

Mr. HASTERT. Dr. Weldon, do you have any questions?

Mr. WELDON. I just had a quick one for Mr. Cunningham. How did we get to where we are, assuming your analysis here is correct—and I believe there is some validity in what you're saying—going from a society that's willing to take chances to—a risk free society. You know, was it Vietnam? Was it Hollywood playing a role? Or is it the trial attorneys? I mean, how did we transition to where we are now, assuming your analysis is correct? Is it all of the above?

Mr. CUNNINGHAM. No. I think I could be a little bit more specific than that. It's quite a political statement. I believe that for 30 or 40 years in this country we have been moving toward what's been characterized as a liberal philosophy that wants to do things for people, not hold people responsible, not challenge them. You know, every time you turn around there's talk about safety nets instead of meeting obligations, taking a challenge, being responsible for yourself and your own results.

It takes a lot longer discussion than I have here to say how that slippery slope got started. And each time it moves slowly and inexorably along we almost forget where it started at one time. But I believe that is a part of it. It's a difference in the kind of philosophy that has been projected in this country for many years. I think I see a swinging of the pendulum back to some degree. But as long as we don't hold people accountable for their actions so that when they do take a risk they see that there's both a possibility for reward and failure.

I'm one of those that believe that it's a tremendous luxury that we have in this country—is the right to fail. Because without the right to fail there can be no real wins, no real victories. It's the opposite side of the same equation and we have to have that opportunity. You have to be able to see the failure in order to know that you want to succeed next time. How many people do you know; how many stories have you heard in this country of those who have tried and tried again and eventually they succeed tremendously?

We have the greatest society in the history of the world to allow that to happen. If we don't kill it, it will go right on happening. But it's our responsibility to see that it doesn't stop.

Mr. WELDON. So if I understand you correctly, it wasn't Hollywood, the trial attorneys, it was Washington, DC that has led us down this path?

Mr. CUNNINGHAM. Of those—the characters that you named, I would say yes, Washington is probably more responsible than the others.

Mr. WELDON. Well, I've only been doing this 3 years, sir, don't hold me accountable.

Mr. CUNNINGHAM. I don't hold you responsible.

Mr. WELDON. I yield back the balance of my time.

Mr. HASTERT. Well, I thank this panel. You've been incredibly candid. You've given your time and I know it's a precious commodity. We've had you before us almost 2½ hours, which is more than we should ask anybody to have to do. Thank you very much.

I just have to be remiss. We've talked about Mr. Howard's film. Dr. Aldrin, I understand that you're writing a book, "Encounter With the Tiger." It's a space analogy and taken from a lot of your own experiences. And I'm sure you're going to get a lot more people involved in what space is all about through this endeavor. So, thank you very much. And thanks for being with us today. We really appreciate your candidness and contribution.

If I may, I would ask our second panel to come forward. If I may ask, I would ask our second panel to stand and be sworn in before I formally introduce each of you.

[Witnesses sworn.]

Mr. HASTERT. Let the record show that the witnesses responded in the affirmative. Please be seated, gentleman. I'd like to formally welcome our second panel: Dr. Peter Glaser, who served as a project manager for *Apollo 11,* Dr. Richard Berendzen, a professor of physics at the American University, Dr. David Webb, who serves as a consultant to developing university and research programs in space science, and Dr. David Criswell, who serves as director of the Institute of Space Systems Operations in the University of Houston.

And gentlemen, I'm going to ask you if you could kind of summarize your statements. We'll try to keep them in 5 to 7 minutes, in that area. Your written testimony will be entered into the record. So gentlemen, thank you very much and please be seated. Dr. Glaser.

STATEMENTS OF PETER GLASER, VICE PRESIDENT, ARTHUR D. LITTLE, INC.; RICHARD BERENDZEN, PROFESSOR OF PHYSICS, AMERICAN UNIVERSITY; DAVID CRISWELL, DIRECTOR, INSTITUTE FOR SPACE SYSTEMS OPERATIONS, UNIVERSITY OF HOUSTON; AND DAVID WEBB, CONSULTANT, SPACE SCIENCE AND ENGINEERING

Mr. GLASER. Mr. Chairman, I am delighted to be able to——

Mr. HASTERT. If you'd all pull those mics up. It's noisy in here. You almost have to talk right in them to get a good coverage. So I'm sorry. Dr. Glaser.

Mr. GLASER. I'm delighted to be invited to speak on a subject which has been of interest and my major effort over the past 40 years. And that is to look at the Sun and see the best way that we can get solar energy converted in a way which we can then beam back to Earth to serve the major needs we see in a global sense.

When I first came up with this concept in 1968, officially, when I talked about it, it looked like science-fiction. President Kennedy's plan to land a man on the Moon within 10 years was considered a great gamble. I believe that this subject from power from space for use on Earth is a logical outgrowth of all the work that we have done in the country in space because it is not just something that people will admire as a result of prowess. But people will require, because of the necessity to continue to live a better life and to ensure that we not destroy the ecology of the Earth by going the wrong way.

Therefore, I am an enthusiast for solar energy in space and on the ground. I have had the privilege of testifying before both Senate and House committees, and I would refer much of the basic and a lot of the information that I have presented there for you to examine. I also will present you more updated information. Now, it's important that NASA and the Department of Energy studied this whole solar power satellite aspect from 1970 to 1980, and the conclusion was that no single constraint was identified which would preclude the development of solar power satellites—just a name I've given it—for either technical, economic, environmental or societal reasons. That was the conclusion.

Now, in the year 1995–1996 NASA performed a study. And that study concluded—I just got the final report—new technologies and system approaches developed in the past 15 years have the potential to make solar power satellites far more feasible than was traditionally believed. That was the latest information from NASA. I believe that power from space should be an integral part of global development goals. It is an acceptable approach to decrease the unsustainable rate of population growth by meeting the insistent demands for higher living standards.

Currently we the population reaching some 10 billion people by mid 21st century, and one half will live in cities by 2000. And the current migration of 150,000 people per day into cities will increase to about 250,000 with some major effects. Today we hope to reach the goal of 3 kilowatts per person, which is about 30 billion kilowatts. Now, that's thousands of modern nuclear power plants with problems we have not solved yet.

Therefore, increasing energy supplies and generation methods compatible with the ecology at affordable costs will be required on a global scale. There is a widening recognition that power from space is relevant and beneficial to life on Earth. And the growing international interest is approved there of. Because today people are working on the subject in Canada, in China, in Europe, India, Japan, Russia, Ukraine, and certainly the United States. And these are things that are in the literature for everyone to see. This is not just some hearsay.

Space power systems have been demonstrated of increasing scope with wireless power transmission across limited distances on Earth, maintain high altitude long endurance aircraft forever, if you want, up in air, and beaming power from a rocket from a spacecraft, which was done by the Japanese. We know that we can do this kind of technology because it is based on 100-year old science and technology developed by Hertz, developed by Nikola Tesla.

I have proposed a SPS—solar power satellite—development program to permit near, mid and long-term benefits of this application. We need to have an appropriate framework for these operations. Because this eventually will be international, just as communication satellites are international. And this international technological community has shown that the objective of solar power from space for Earth can be realized, and that well-planned future efforts can achieve the promise of space endeavors which you have just heard from the previous panels.

All of these things can be the basis for doing the applications I'm talking about. I know the first development steps are always the hardest to take, to demonstrate that the promise of power from space is real, by placing increased reliance on the inexhaustible energy of the Sun will ensure that all forms of life can continue to flourish on Earth. Thank you, Mr. Chairman.

[The prepared statement of Mr. Glaser follows:]

SOLAR POWER FROM SPACE FOR USE ON EARTH

Background

Nikola Tesla, the inventor of wireless radio and electrical generating machinery, stated in 1881: "...Throughout space there is energy. If static - our hopes are in vain; if kinetic - and this we know it is for certain - then it is a mere question of time when men will succeed in attaching their machinery to the very wheel work of nature."

Our article "Solar Power Satellites", published in Science, November 1968*, was based on the presentation to the Intersociety Energy Conversion Conference, Boulder, Colorado, August 16, 1968. The conclusions offered in Science were then, and are now still appropriate:

"We should not underestimate the development efforts that will be required to construct, launch, and operate the suggested Solar Power Satellite, SPS, (with the objective to provide power to Earth continuously). At this time, solution of most of the difficulties is expected to be within the projected capabilities of systems engineering, and will not require the discovery or development of new physical principles. The search for power from the Sun appears to be less of a technological gamble than it seemed when President Kennedy first announced the objective of landing a man on the moon, and returning him to Earth, in ten years. In fact, projects such as the development of SPS may prove to be a logical outgrowth of achievements in space, and may help lead the world into an era in which an abundance of power could free humans from their dependence on fire."

The conquest of space, was demonstrated by Neil Armstrong when he set foot on the moon on July 20, 1969, and told the world: "That's one small step for a man, one giant leap for mankind." It was this "small step" that made it worthwhile for NASA and the U.S. aerospace industry to consider our 1968 proposal to obtain power from space.

* Selected References on page 7

Our first presentation on SPS at NASA was made to Dr. James Fletcher, NASA Administrator, in 1970. Subsequently NASA Lewis Research Center, Marshall Space Flight Center, and Johnson Space Center performed a series of studies on the required technologies until 1976. The Department of Energy in cooperation with NASA conducted the SPS Concept Development and Evaluation Program with the objective: "to develop, by the end of 1980, an initial understanding of the technical feasibility, economic practicality, and societal and environmental acceptability of the SPS concept."

This assessment concluded that no single constraint was identified which would preclude the development of SPS for either technical, economic, environmental or societal reasons, that the NASA SPS Reference System to supply 5 million kW of continuous power on Earth is amenable to evolutionary development, and that the SPS is technically possible.

In view of the promising results of SPS assessments by NASA and the Department of Energy, Congressman Flippo, Alabama, introduced H.R. 11725 in the 95th Congress, 2nd Session, March 22, 1978: "...to provide for a research, development, and demonstration program to determine the feasibility of collecting in space solar energy to be transmitted to earth and used to generate electricity for domestic purposes." Hearings before the Subcommittee on Space Science and Applications and the Subcommittee on Advanced Energy Technologies and Energy Conservation, Research, Development and Demonstration, of the Committee on Science and Technology were held in April 1978 but the bill did not receive due consideration.

The National Commission on Space report, Pioneering The Space Frontier, had a positive view of SPS: "The ideal space enterprise would have a stable, predictable, very large market on Earth, a potential for export sales, and once established, would not be dependent on Earth-to-orbit transportation costs to generate continuing revenues."

From today's perspective of global challenges which will have to be faced in the 21st century, the SPS program, if it had been pursued by the United States as proposed by NASA, could have led to a convergence of current activities by space-faring nations to meet the political, economic, and ecological challenges in the 21st century, as there are several concerns with the viability of currently known global energy supply options.

The "Fresh Look" Study on future SPS systems performed by NASA during 1995-96, included: "... architectures, innovative systems concepts, technologies and the associated infrastructure based on new technologies and system approaches that emerged during the past 15 years which have the potential to make space solar power far more feasible than is traditionally believed. This study concluded: Very promising results of this study emerged from preliminary market and economic analyses."

Rationale for Power from Space

Power from space should be an integral part of global industrialization goals to meet the insistent demands for higher living standards of the exponentially growing population, estimated to approach 10 billion by mid-21st century. One half of this population will live in cities by 2000. The current migration into cities of 150,000 people per day will increase to about 250,000 per day in 25 years. Future cities may have to be built in the oceans off the coasts of continents to conserve land for food production, as discussed at the "Ocean Cities" Conference, Monaco, November 20-23, 1995, with power possibly supplied by SPS to offshore receiving antennas.

An acceptable approach to decrease the unsustainable rate of population growth over time is to raise the living standard of the people. To approach the goal of 3 kW per person, about 30 billion kW would have to be supplied to meet the demands of the global population by mid 21st century. To meet this goal increasing energy supplies and generations methods compatible with the ecology, and at affordable costs will be required on a global scale.

Alternative energy development on a global scale will begin to be dominant in the post-2020 period, because of the extended construction lead-times of conventional power plants in various planning stages, and the associated energy resources infrastructure investments . Over the next three decades capital requirements are estimated to range between 13 to 20 trillion ($1990) in the energy sector to keep pace with the doubling of energy use in emerging economies where most of the population growth will occur. The latter amount equals the total global economic output in 1990.

There will also be an unprecedented shift in economic activities during the next decades, with several emerging economies growing at least twice as fast as those of nations with mature economies. The impact of these economic activities will result in greatly increased consumption of available fuels. This will increase the potential degradation of the Earth's ecology if primary reliance will be placed on currently used energy sources to meet the foreseeable global energy demands. In addition finite terrestrial energy resources have already passed their peak availability. The economic impacts of potential energy cost escalation of terrestrial energy sources by mid-21st century have not yet been fully taken into account.

The Power from Space Options

There is widening recognition that SPS and associated benefits are of increasing relevance and importance to life on Earth. Increases in living standards would lead to reduced population growth and mitigate the projected negative impacts on the Earth's ecology.

Wireless power transmission is key to accessing the inexhaustible energy of the Sun with SPS. The use of wireless power transmission for SPS is based on the discovery of Hertzian waves in 1884, and efforts by Tesla to demonstrate this technology for long distance power transmission on Long Island, New York, in 1907. The practical uses of effective wireless power transmission, reception and conversion have been developed during the past 50 years. As a result of the current wide uses of wireless power transmission for applications in homes, and industry, the required technologies meet international standards to ensure the health and safety of the public. In addition the capabilities of a wide range of space systems including direct conversion of solar energy to electricity in space have advanced considerably.

Space power system investigations of increasing scope and complexity conducted in the past 30 years included: wireless power transmission over limited distances on Earth, maintaining high-altitude, long-endurance aircraft on station, power relay satellites to transmit power across intercontinental distances, SPS located in Earth orbits and on the lunar surface. Such projects will be important to demonstrate reliable and effective operations, to meet agreed upon performance requirements, to comply with applicable standards, regulations and the existing legal framework protecting the public and the environment, and to raise the required investment funds from public and private sources.

Advances in space technologies have made it possible for: satellite communications to create the Global Village, weather predictions to provide more accurate information, remote sensing data to serve a growing market, and spacecraft to obtain scientific data about other bodies in the solar system. There is a distinct possibility that future space operations would make it possible to use extraterrestrial materials and solar energy, in combination with terrestrial resources to benefit life on Earth. There is a growing understanding of the range of issues that are significant for the evolutionary development of SPS as alternative global energy supply options.

The growing international interest in SPS today includes activities in Canada, China, Europe, India, Japan, Russia, Ukraine and the United States, as reported at meetings of United Nations Agencies, and professional societies. These activities will be discussed at the SPS '97 Conference, August 24-28, 1997, Montreal, Canada. The extensive international literature on technical, economic and societal issues, indicates that there are no known show stoppers to the development and introduction of SPS. Therefore, this global option is worthy of receiving serious consideration by industry and governments.

There are many specific issues pertaining to SPS : frequency selection, operational safety in space and on Earth, integration with terrestrial power grids, location of receiving antennas on land and offshore, and compliance with constraints imposed by economic considerations, ecological requirements and societal acceptance.

A stepwise SPS development program will permit near-, mid-, and long-term benefits of applicable technologies to be demonstrated to satisfy potential investors, to obtain international cooperation, and to comply with legal and regulatory frameworks applicable to space operations. This approach also will include arrangements with industry to satisfy future power demands, and to meet the requirements for global beneficial space activities as is already the case for telecommunications.

Since currently used energy sources face diverse challenges which will limit their expansion on a scale essential to ensure the desired access to energy, and to achieve the goal of equitable and sustainable development, it is fortunate that parts of the solution, including terrestrial renewable energy sources to meet future global energy needs already exist.

Now is the time to select the most desirable power generation options before new commitments are made that would result in long-term and potentially deleterious effects on all forms of life. These options include terrestrial renewable energy sources as well as the SPS to protect this unique planet and its fragile ecology, and to ensure that the energy of the Sun will continue to maintain life on Earth.

In the 21st century SPS can be the key component of the global energy supply infrastructure with long-term benefits, capable of safeguarding the ecology of the Earth, and ensuring equitable and sustainable future benefits.

To achieve the goal of providing energy from space for use on Earth, SPS development and implementation programs will have to be planned on a scale and time frame extending well into the 21st century. When Arthur C. Clark proposed in 1945, that global communications should be based on orbiting satellites, his proposal was considered to be in the realm of science fiction, and highly unlikely to he realized. Achieving the goal of global communications is today accepted as essential for the functioning of the global community.

There are no assured or easy solutions to the major global challenges faced by society in the 21st century. The SPS holds significant promise as a unique option to ensure the tangible benefits for generations to come. One of the significant advantages of developing SPS is that there are many intermediate steps that can be taken, with each step justified on its own merits. The lessons learned may even permit future endeavors which today can only be seen in broad outline such as diverting asteroids or comets from potential collision with Earth.

The results of investigations, experiments, demonstrations and future plans by the international technical community on this subject are available. They show that power from space for use on Earth is not a dream, and that well-planned efforts can achieve the goals and potential of future space endeavors. The first development steps are always the hardest to take to demonstrate that the promise of power from space is real. There is every reason to be confident that the power from space option based on the Sun's energy can meet the challenges humanity will face on Earth in the future.

As Prof. J.D.Bernal foresaw in 1969:"...It may be that in the future, man will be indifferent to stars except as spectacles, but if (and this seems more probable) energy is still needed, the stars cannot be allowed to continue in their old ways, but will be turned into efficient heat engines."

Sir Arthur C. Clark when asked about the energy shortage of 1973 replied: "There is no shortage of energy, there is a shortage of intelligence".

We can only partially project the benefits that will be available when the energy of the Sun is combined with known and proposed space technologies. The Wright brothers, after they flew their airplane at Kitty Hawk, could not foresee the impacts global aviation has today. Today we can discern only the outline of a new era, when the aspirations of humanity can be realized in harmony with nature. Placing reliance on the inexhaustible energy of the Sun will ensure that all forms of life can flourish.

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Mr. HASTERT. Thank you, Dr. Glaser. Dr. Berendzen.

Mr. BERENDZEN. Thank you, Mr. Chairman. Thank you, members of the committee. And congratulations on holding this hearing and where you decided to hold it and when. You know, we're surrounded by the icons by this Nation of this century. They're precious to us. A moment ago, I went on the outside and looked at the people. There are thousands of them: men and women and children and grandchildren and grandparents of every race, creed, color national origin, male, female. Do you have any doubt of the interest of space across this Nation?

Those are not astronauts. Those are not scientists. Those are not engineers. But it's the most popular museum in the history of the world. And think of what is here today. Behind us we have lunar landers. Think of the museum a century from now if we have the proper verve. Mars landers. Not just lunar rocks, but Mars rocks, asteroid rocks, water from the moon of Titan, even hydrocarbons from the distant Titan itself. And then consider what all we might do. Even communicate with human beings and habitats elsewhere.

I happened to be at the opening night of Mr. Howard's spectacular film. I saw in northern Virginia in a crowded theater. At the end of the film for the first time in my entire life, I saw everyone in that theater—that jaded audience of Washingtonians—rise to their feet as one, cheering, applauding, screaming in adulation, in part because it was such an expiring movie, but also because it was sheer Americana. It was we, we did and we will again. Well, if I may turn to my comments.

Those who came before us expanded their compass and went beyond. History shows that the peoples who pursued their quests maintained a national vitality and reaped rewards beyond their initial hopes. Our forbearers also looked at the night sky in awe. Many people today want to reach the next frontier, to venture from cradle Earth and to voyage to other worlds. Humans crave exploration. They want to do more than survive. Today we are poised to explore the greatest frontier of all with humans and machines working together.

As this millennium ends this Nation can leave an inspiring and challenging legacy for the 21st century. It can set long-term plans to explore the solar system, place humans on Mars and build outposts off of our planet. For such long-term, far-reaching efforts the final rewards will differ from what we forecast today. Moreover, the most important things in life, those we cherish the most, do not permit a cost-benefit analysis. Try computing the cost-benefit of patriotism or courage or love. But with limited resources and pressing needs, the Nation should consider its desire for and commitment to exploration.

How much do we really want to visit other worlds? Are we willing to pursue work that will bring immediate benefits, but whose major rewards will come in the future. We shall find no hospitable world trivially ready for colonization, and the effort to get there will be substantial. But consider the potential benefits. From a major stimulus of technology, research and development and science education to epochal findings in planetary sciences and many other fields. Such endeavors will boost diverse industries, stimulate much of our national economy, and create jobs at all levels and many disciplines, and present a unique, even historic opportunity for American leadership and the world community by focusing efforts of many nations on this greatest of all human adventure.

Of this we can be sure. Humans will explore Mars and go to the furthest reaches of our solar system and beyond. The insightful question is not if humans will do so, the right questions are who will do it and when. With proper planning, the United States can offer the answer: Americans early in the next century. T.S. Eliot stated, "We shall cease from exploration and the end of our exploring will be to arrive where we started and know the place for the first time." Was he right?

Also, will our voyages of discovery return us to where we started: to our planet, our Nation, ourselves? Through long-term space exploration we can establish our niche in time. Centuries from now, even voluminous history books will truncate much of what engrosses us today: recessions, political races, even mini wars. In time all these will become brief entries in the sweep of human achievement.

But a few extraordinary accomplishments will tower forever. *Apollo 11* landing surely will be one of these. Human landing on Mars will be another. And proof of the existence of life, present or past, on another world would stand as a benchmark in all of time. We wish to explore for tangible reasons too. Such efforts will increase our understanding not only in scientific fields, but also in management, business and even the arts and humanities. Yet another drive compels us to explore. For we are Americans. No other people in modern history have benefited so much from exploration or contributed so much to it as the people of this Nation.

It is our tradition and our culture. It was from the experiment of our democratic society to the reaches of our scientific quest. We are explorers. Without exploration we could not be. For the next generation, for the Nation's third century, space exploration will constitute a natural continuum of the American adventure.

What, then, should this exploration be? Superficially it would be a plan to take robots and then humans to Mars and eventually elsewhere in the solar system. But saying only that would no more encapsulate it than saying that Yosemite is just real estate or the Star Spangled Banner is just a song. Space exploration constitutes many things, tangible and intangible. Among them, science and technology. That to enable the exploration and that that the exploration will enable. Economic benefits prompted by significant stimulus of the Nation's most advanced technologies. Quality of life. All those space exploration deals with other worlds, it's applications are actually down to Earth.

Space exploration could make our lives more comfortable and even more secure. Education, both for future scientists and engineers and for scientifically literate citizens generally. International cooperation, both with our traditional allies and our traditional adversaries; national pride and international respect. Apollo brought pride and respect. Twenty-first century space exploration, even bolder and even more ambitious than Apollo, will do so as nothing before in history.

Young people need to know that their Nation chooses rigorous goals, applies itself resolutely and achieves its objectives. And space exploration will create a new generation of heroes. As historian Arthur Schlesinger, Jr. has argued, “If our society has lost its wish for heroes and its ability to produce them, it may have turned out to have lost everything.”

To undertake such exploration will require courage. It entails risk, even danger. But we should remember Ralph Waldo Emerson’s dictum: “Every wall is a door.” Can we find the door? If we do, will we open it? Shall the Nation continue its bold and daring heritage. Adults ponder these matters, yet they actually belong to the children. This is the stuff of their dreams, and will shape their world. Children gaze at the night sky in awe. Adults, caught up in the day to day concerns can forget the wonder and lose the mystery.

What a loss when that happens. For child-like curiosity has inspired American achievement. Beyond the benefits for space, technology, the economy, quality of life, education and even pride, such exploration is about providing a vision. This undertaking will span decades. Many of its principle beneficiaries are now infants or not yet even born. Our foresight and determination will become their lodestar. More than a major NASA program, a scientific quest or a technological challenge, space exploration is a reaffirmation of American leadership at large and left indelibly on the pages of history.

It is America at its best, doing what only America can do on such a scale: dream, plan, invest, achieve and lead our people and people everywhere to old aspirations, continuing hopes and new accomplishments, lead them to other worlds and to the future. Thank you.

[The prepared statement of Mr. Berendzen follows:]

Those who came before us yearned to expand their compass, go beyond, forge the river, climb the mountain, reach the other side. Once there, the content among them tarried. But others—always curious, always seeking—wanted to know more. They wanted to grasp what was beyond their reach. So they continued—ultimately to cross oceans and span continents. History shows that the peoples who pursued their quests maintained a national vitality and reaped rewards beyond their initial hopes.

While our forbearers traveled past their parents' boundaries, they also looked at the night sky in awe. To them, the heavens brought wonder and mystery. Like the explorers and pioneers before them, multitudes of people today want to reach the next frontier—this time to leave cradle Earth, our birthplace and our home, and to voyage to other worlds ... and thereby to develop new technologies and discover new insights.

What compels us so? Is it genes, curiosity, impatience, destiny beckoning? Whatever the impetus, humans crave exploration. They want to do more than survive. They want to journey, to experience, and to know. Today, we are poised to explore the greatest frontier of all—the endless boundaries of space—and to do so with humans and machines working together as colleagues. As this millennium draws to an end, this Nation—and only this Nation—can leave an inspiring, challenging, visionary legacy for the 21st century. It can set long-term plans to explore our solar system, first with robots and then with humans. It can place humans on Mars, build outposts off of our planet, and propel us into the future.

But why should we explore, be daring, go so far? In part because we are the new Columbuses and space is our New World. Five centuries ago, in the Age of Exploration, intrepid souls probed new frontiers. Today that same drive, curiosity, and zest for the unknown motivates a new generation of explorers. But in Columbus' time, disease, famine, and poverty racked much of Europe; in our day, social ills still abound. Yet, in the 15th century, some government leaders and brave adventurers saw wisdom in investing a small percentage of available resources in going beyond their kin. At the outset, they assumed returns they might gain; ultimately, though, this option on the future yielded unexpected rewards. So too will it be in the 21st century. Clearly, the Nation must address its social needs and must spend taxpayers' money prudently and only when necessary. Nonetheless, it should spend—actually, invest—a small portion of its total GNP and human effort in exploration and the future.

We can be sure that for such long-term, far-reaching efforts as planetary exploration, the final rewards will differ dramatically from whatever we forecast today. What is more, the most important things in life—those we cherish most—do not permit a cost-benefit analysis. Try computing the cost-benefit of patriotism or courage or love or children.

Even so, with limited resources and pressing needs, the Nation should consider its desire for and commitment to exploration. How much do we want to visit other worlds—ones like our own and ones vastly different? Will we attempt feats never tried before? How much do we want to grasp what lies beyond our reach? Are we willing to commit ourselves for decades to arduous work that will bring immediate benefits but whose major rewards will come in the future?

Unlike Columbus found in his New World, we shall find no hospitable habitat in space ready for colonization, and the effort to get there will be substantial. But consider the potential benefits—from a major stimulus of technology, research & development, and science education to epochal findings in planetary sciences and many other fields. Such endeavors will boost diverse industries, stimulate much of our entire national economy, and create jobs at all levels and many disciplines. They present an unique—even historic—opportunity for American leadership in the world community by focusing efforts of many nations on this greatest of all human adventures. It would bring national pride and international respect.

Of this we can be sure—humans *will* explore Mars and go to the farthest reaches of our solar system and beyond. The insightful question is not *if* humans will do so, for they will. The right questions are *who* will do it and *when*? With proper planning now, the United States can offer the answer: Americans, ideally with international partners, will start doing so early in the next century. And by the 50th anniversary of Apollo 11, in the year 2019, humans will have gone from that first daring yet cautious step onto a new world to having established permanent habitats far from Earth.

WHY EXPLORE AT ALL?

T.S. Eliot stated: "We shall not cease from exploration and the end of all our exploring will be to arrive where we started and know the place for the first time."

Was he right? Will we always explore? And ultimately will our voyages of discovery return us to where we started—to our planet, our Nation, ourselves? When we achieve this goal and at last realize some age-old dreams—when we live and study on other worlds, holding them in trust for posterity, while examining them to understand better our own heritage and future—will we know the place from whence we came for the first time?

In an essay entitled, "Bubble of Blue Air," published in 1968 after Apollo astronauts took their first photograph of Earth from space, poet Archibald MacLeish wrote: "To see the Earth as we now see it, small and blue and beautiful in that eternal silence where it floats, is to see ourselves as riders on the Earth together, brothers on that bright loveliness in the unending night—brothers who *see* now that they truly are brothers."

In the 19th century—as a result of exploration— Americans developed a continental consciousness. While still parochial in many ways, they began to envision a country continent-wide. In the 20th century—as a result of television, jet travel, a global economy, the Internet, and perspectives of Earth from space—Americans and many other peoples are developing a global consciousness. While still highly nationalistic, in the 21st century—as a result of expanding technology, interdependence, and ambitious and inspiring initiatives in space—perhaps humankind can develop a more cosmic consciousness. As a planetary species rather than rival national groups, perhaps we can explore the solar system together.

In the past, many voyages of exploration were launched for the spoils they could return or the colonies they could appropriate rather than the harmony they could produce. For space exploration, commercial rewards *will* accrue. Significant long-term space exploration will drive technology, reap unexpected scientific rewards, and will bring economic benefits. Even so, except for some speculative prospects—such as collecting solar energy from space and mining the moon and asteroids for certain minerals or possibly for nuclear fuel—few astronomers seek great natural resources from our nearby celestial neighbors. Nor can any government claim them for territories. By international agreement, no nation—including the first to arrive—can own another world. Our impetus to explore continues a lineage to the Babylonians and Phoenicians, Marco Polo and Ponce de León, Francis Drake and James Cook, Lewis and Clark. Like our predecessors, we too are curious and seek adventure as well as rewards. Nonetheless, we shall not pursue space exploration to find new trade routes, claim land, or find fountains of youth.

Instead, we yearn to explore for other reasons. Aside from the ones I have mentioned, some people wish to influence history. Historian Robert Heilbroner has argued for the value of making human history. "It is a crushing spiritual blow to lose one's sense of participation in mankind's journey," he has stated. And he has gone on to say that, "If we are to meet, endure, and transcend the trials and defeats of the future ... it can only be from a point of view which, seeing the future as part of a sweep of history, enables us to establish our place in that immense procession ..." Through long-term space exploration initiatives, we can establish our niche in time.

Centuries from now, even voluminous history books will truncate much of what engrosses us today. Recessions, political races, even many wars—in time, all these will become brief entrees in the sweep of human achievement. But a few achievements, a few extraordinary accomplishments, will tower forever.

The Apollo 11 landing surely will be one of these. Human landing on Mars will be another. Indeed, it and other related space activities could be benchmarks of the next millennium.

We wish to explore for tangible reasons, too. Such efforts will increase our understanding not only in scientific fields but also in management, business, and even the arts and humanities. Their impact on research & development will enhance American technology in many fields. In time, the expansion of knowledge and perspective from space exploration will effect almost all sectors of American life—from astrophysics to metaphysics, from electronics to aesthetics, from rocketry to religion. Economic benefits will come as well. And all of this will result from an investment—an option on our future, a commitment now with near-term returns and long-term rewards.

Yet another drive compels us to explore. We are Americans. No other people in modern history have benefited so much from exploration, or contributed so much to it as the people of this Nation. It is our heritage, as it will be our children's. It is our tradition and our culture: It was from the discovery of the Western Hemisphere to the opening of the American West, from the experiment of our democratic and free society to the reaches of our scientific quests. We Americans are explorers; without exploration, we would not be. For the next generation—for the Nation's third century—space exploration will constitute a natural continuum of the American adventure.

As President Ford said on the Nation's bicentennial: "The hallmark of the American adventure has been willingness—even an eagerness—to reach for the unknown ... Americans and their ancestors have been explorers and inventors, pilgrims and pioneers, always searching for something new—across the continent, across the solar system, across the frontiers of science, beyond the boundaries of the human mind ... Our country must never cease to be a place where men and women try the untried, test the impossible, and take the uncertain paths into the unknown."

Advantages of Space Exploration

What, then, would this space exploration be? Superficially, it would be a plan to take robots and then humans to Mars and eventually elsewhere in the solar system. But saying only that would no more encapsulate it than saying that Yosemite is just real estate or "The Star Spangled Banner" is just a song. Space exploration constitutes many things—some tangible, others intangible. Among them:

- Science, both science to enable this exploration and science this exploration will enable. Scientific breakthroughs can come in astronomy, planetary science, exobiology, physiology, life sciences, medicine, geology, and a host of other fields. For example, study of bone mineral loss in space may help us understand better what causes osteoporosis and how to prevent it. And studies of Mars can help explain the causes and effects of ozone depletion generally and how to control it, as well possibly provide us with insights into the origin and development of life.

- Technology, both technology required for the exploration and technology derived from the exploration. Major technological progress requires challenges across a range of fields, not just a highly focused effort in one area. Both World War II and the Apollo program made such demands and yielded vast technological gains. Space exploration will too.

- Economic benefits, prompted by significant stimulus of the Nation's most advanced technologies. In time, other commercial rewards will come as well in fields ranging from food preservation to fabrics, from microelectronics to super computers, from fiber optics to laser surgery, from remote sensing to artificial intelligence, from communications technology to alternative fuels. Indeed, in the next century space exploration can help drive the American economy and competitiveness, and the great American industry will participate along with government.

- The quality of life. Although space exploration deals with other worlds, its applications are down-to-Earth. Space research in strong, lightweight metal alloys and plastics will support such industries here on Earth. Miniaturization of electronic components will lead to future designs for day-to-day applications. Sophisticated, portable, lightweight, health monitoring equipment for space exploration can be used anywhere on Earth. Automation and robotics for space exploration can be applied from the automobile industry to undersea research. High-output portable power supplies for space exploration can become prototypes for energy sources at remote industrial or military outposts on Earth. In short, space exploration can make our lives more comfortable and more secure.

- Education, both for future scientists and engineers and for scientifically literate citizens generally. During the Apollo era, many students studied math and science; Apollo catalyzed their interest. Space exploration can help stimulate student interest in technical subjects, broaden the range of students so interested, and better educate workers for all sectors of American life. It can provide the Nation with a highly trained workforce available for other purposes as well.

- International cooperation, both with our traditional allies and our traditional adversaries. This can increase cooperation, spread costs, build trust, and produce enhanced results as a global effort on peaceful pursuits following American leadership.

- National pride and international respect. Apollo brought pride and respect. And 21st century space exploration—even bolder and more ambitious that Apollo—will do so as nothing before in history.

- A sense of adventure, daring, and even heroics. Unquantifiable, these intangible attributes possess enormous value. Young people need to know that their Nation plans for the future, chooses rigorous goals, applies itself resolutely, and achieves its objectives. The Nation will set an example for youth. And it will create a new generation of heroes—men and women of various ages and different races who plan the exploration, build the equipment, and take the voyages. These people, working for the sake of new knowledge and national betterment, will be as respected in the future as Mercury 7 astronauts were in the past. As historian Arthur Schlesinger, Jr. has argued: "A free society cannot get along without heroes ... If our society has lost its wish for heroes and its ability to produce them, it may have turned out to have lost everything as well."

To undertake such space exploration will require courage, for the effort faces almost insuperable technological challenges. We must be resolute and remember Ralph Waldo Emerson: "Every wall is a door." Can we find the door? If we do, will we open it? Shall the Nation continue its heritage of exploration? Do we still wish to push the boundaries? Such exploration can bring us a new Renaissance. Dare we pursue it?

Adults ponder these matters, yet such futuristic issues actually belong to the children. They is the stuff of their dreams and will shape their world. Children gaze at the night sky in awe. Adults, caught up in day-to-day concerns, can forget the wonder and lose the mystery. What a loss for the Nation when that happens, for child-like curiosity has inspired American achievement.

Over and above the benefits for science, technology, the economy, quality of life, education, and even pride, such exploration is about providing a vision for our children. This undertaking will span decades. Many of its principal beneficiaries are now infants or are yet unborn. Our vision and our determination will become their lodestar.

More than a major NASA program, a scientific quest, or a technological challenge, the whole of such space exploration will vastly exceed the sum of its parts. Ultimately, it is a reaffirmation of American leadership, writ large and left indelibly on the pages of history. It is America at its best, doing what only America can do on such a scale: dream, plan, invest, achieve, and lead—our people and people everywhere to old aspirations, continuing hopes, and new accomplishments—lead them to other worlds and to the future ...

Mr. HASTERT. Thank you, Doctor. Dr. Criswell.

Mr. CRISWELL. Thank you, committee chairman and subcommittee members. I hope you have a copy of this presentation. I'll be making reference to pages four and six. I'd like to talk with you about the lunar solar power system to supply Earth with commercial electric power. It's generally not recognized——

Mr. HASTERT. Doctor, would you pull the mic closer?

Mr. CRISWELL. Yes. Is this better?

Mr. HASTERT. That's great.

Mr. CRISWELL. It's generally not recognized, but the essential assumption on most energy projections is that the world will stay poor, most people will stay impoverished. Worldwide prosperity in the 21st century requires more energy than can be supplied by conventional, non-renewable sources such as coal and shale and non-breeder uranium systems, or even terrestrial solar power. And this includes biomass and photovoltaic.

Present power systems are limited by their fuel resources, the increasing costs of non-renewable fuels, and by the very high cost of a terrestrial solar renewable systems and the backup power supplies that they need and long distance transmission lines. In addition, they all impact the environment. I think a goal for the U.S. space program and even the world space program is that by 2050 we should supply all 10 billion people in the world then with at least 2 KW each of electric power. That's a goal of 20,000 gigowatts of electric power.

That's about six times more power than the world produces now. It's equivalent to what is required by Western Europe to provide the high standard of living that they have there. I think a solar energy system based on the Moon can provide this electricity and provide it at a cost that's a about 3 to possibility about 30 times less than the wholesale cost of electricity now. You'll be delivering the power by engineered photons—microwaves—in such a way that the system is intrinsically environmentally clean, and rather than depleting Earth's resources can actually increase the resources of Earth.

There is enormous growth capacity in this system. I believe that it can grow to somewhere between 100,000 and 1 million gigowatts of delivery power, far more than we need now and enough for several centuries of growth. I'd like to refer you, if I could, to the fourth page of that presentation set, which gives a schematic of this power system seen from outside of a city on Earth. The Sun is the source of the power. It's an operating fusion reactor. The Moon is the recipient of the solar power.

It exists, it's in the light orbit, the same face always faces Earth. And you build power bases on the two limbs of the Moon as seen from Earth so that one or the other is Sun-lit and can deliver the power. The power is handled by changing sunlight to electricity to microwaves and then to controlled, low intensity beams that deliver the power down to very lightweight microwave receivers on Earth.

All of the key technologies and operations surprisingly enough are already demonstrated. There's no fuels. There's no furnace. There's no ash or long distance transmission lines in this system or even massive equipment. It can be a very long life system that dependably delivers power, but very importantly is independent of the biosphere. The beams are unaffected by rain, fog, dust and the things that normally could interfere with ground-based power.

If you could refer to videograph No. 6, or slide 6 there. That's a picture of a prototype power base, a demonstration power base on the edge of the Moon. In that place the Earth always stays fixed in the sky, eternally and each base is huge. But it's composed of small units called power plots. There would be tens of thousands of these. And this is simply a representative view of one type. The power plot consists of local solar arrays, small microwave transmitters and reflectors, all primarily fixed on the lunar surface.

And they would be made out of the local materials. I think the talks that you heard by Buzz Aldrin by other astronauts and the evidence that you see around here of our visits to the Moon are examples of one of the best investments this Nation could have conceivably made in its future. We know what's there. We know the common resources. And we know that we can convert into these fairly simple power components that I've just described.

They would be generated by mobile factories that are on the Moon and put out hundreds to thousands of times their own mass in components. What that means is the cost of transportation does not affect the cost of power in a strong way. All of these steps can be clearly demonstrated on Earth before you ever go back to the Moon. And the industrial size demonstration can be done for a fraction of the present U.S. investments in space.

In summary, this lunar power system, I think, can provide Earth a second source for its critical energy needs on a worldwide basis. This will be net new energy that can be used to underpin clean environmental growth and new prosperity that's not possible in a way when you use depletable resources. From the standpoint of the vision spoken about by our previous speakers, this will enable the economic establishment of a two-planet economy—the Earth and the Moon are the two planets—which can grow self-sustained.

A future space program could literally grow off the taxes generated by the new economic growth of this two-planet economy and fundamentally will provide humanity a way to grow into its lunar space and prosper. Thank you.

Mr. HASTERT. Thank you, Doctor. Dr. Webb.

Mr. WEBB. Chairman Hastert and members of the committee.

Mr. HASTERT. I would ask you to speak into the mic. It's a little loud in here and a lot of background noise.

Mr. WEBB. All right. Can you hear me now?

Mr. HASTERT. Yes.

Mr. WEBB. Chairman and members of the committee, it's my honor and pleasure to be here today. I must admit to a certain degree of déjà vu when listening to the excellent presentations you have had, particularly by the members of the astronauts—Buzz Aldrin, Walter Cunningham and Story Musgrave—and also the excellent presentation by Ron Howard.

I had the honor of being a member appointed by President Reagan to the National Commission on Space, which you may remember was a congressionally mandated study of the future of the American space program through the year 2030 that took place in 1984 and took a year. We reported in 1985, in a 215-page document that outlined all the possibilities and many of the problems that we have discussed today. For the record, "Pioneering the Space Frontier" was the name of the commission report.

This is the first section—and I think that you have it in your briefing papers. I would like, with your permission, Mr. Chairman, to have this first section read into the record.

Mr. HASTERT. Without objection.

Mr. WEBB. Thank you. The whole concept of what we have heard today and the whole concept of what we heard in the commission was the necessity for the United States to maintain its lead in space. And at the present time we have dropped the ball in a very large way. The problem that we see right today—when we announced in this commission report, we should by the year 2000 have developed a low-cost cargo transfer vehicle, a low-cost manned space vehicle, we would not just have a space station, which we were told would be in operation by 1994, but we would have a space port by the year 2000.

By the year 2005 we were suggesting we should be back on the lunar surface, we should develop mining operations on the Moon, we should learn how to live off-Earth. And by the year 2010, we would have a full-scale manufacturing and replenishment facility on the Moon. And we would then build the Mars space crafts, including Buzz Aldrin's cycling space ships, and we would leave for Mars, and we would be on Mars by the year 2019.

That was 11 years ago, Mr. Chairman. In that 11 years, if you look today at what has happened, not one single element that we were suggesting that should be in place by the turn of the century has even been begun except the space station, which is 8 years late and $25 billion over budget. And all the other elements that we're talking about—a reusable space vehicle, now—it will be 8 years to 10 years before those space vehicles can possibility come on stream.

We need—your committee, if I may say, needs to ask what has happened that causes the United States, the preeminent technological power in the world, to be unable to produce a space station in the time that the President challenged the Nation to do it: 10 years, one decade. We have not yet, as I think it was Walt Cunningham said, "got one nut or bolt in space at this time."

There is something that is the matter. If I may make a suggestion—and I do so in my testimony. The manner in which we develop technology, the way we regulate technology in this program, is unique to the United States. We are the only industrial Nation in the world that demands an annual review of every technology program that we have underway. In doing that, we invite a growing opposition as the program moves along and becomes more expensive. And we invite every year—it will be reexamined and either cut back or apportioned or reapportioned. And we're back to square one.

We cannot ask our engineers and scientists to keep this Nation in the forefront of technology if we are second-guessing them every single year. This, I understand, is a congressional prerogative. I understand that the monetary power of the budget is a prime thing for Congress, as it should be.

However, there may be other ways. I am suggesting in my testimony the creation of a technology development fund which would operate very similar to the great foundations of the world in which the Congress would apportion a certain amount of funds every year to cover the new technology programs that were going and would give the money for a set period of time, which I would like to see in 5 years. But you probably could not do that. But maybe even 4 years: two congressional terms. If that were done, there would be a steady funding of technology. If there was steady funding of technology we would have a space station in space now. We would have single stage to orbits, reusable space vehicles, and we would not have this desperate cancellation of programs.

The National Air and Space Program was to give us a single stage to orbit airplane. We spent $2.4 billion. We worked for 5 years. We made enormous advances. And then the program was canceled. No question. Gone. This is damaging our leadership in space. All the other nations in the world once upon a time believed that we had such a lead in the development of space that they would never be able to catch up. And yet look at it today. Because of the fact that we have not created a new launch vehicle in the last 20 years, we are falling behind. We have lost 70 percent of the world space launch market in the same period of time.

It is a tragedy of enormous proportions. We don't see it until it comes and bites us. We are the only industrial space Nation that has not built a rocket engine in 25 years. The Russians have built seven. The Chinese have built three. The Japanese and Europeans have built two each. India has built two. We have built none. And then, we wonder why we're losing the space market.

If we do not understand and if we do not unleash our programs to be able to be fulfilled the way we try and develop them in the beginning, we will always be doing that. And in doing that, this country will lose its leadership as sure as we are here today. It is a given where there are very powerful entities, not the least of which is China, which is just starting, Japan, Russia. Russia right now is in plenty of trouble. But they will get together. And they are a powerful competitor.

We honestly need to review how it is that we handle our space technologies and how we handle technologies generally, and try and develop new ways. This is a real challenge to the Congress and it's a real challenge to the entire community to be able to adjust to something new. But that is what I would like to see happen, because this is the greatest country in the world. And we must, lead the space race, if that is what it is—or our venturing out onto the next frontier. Thank you.

[The prepared statement of Mr. Webb follows:]

About the Authors

David C. Webb

David Webb is nationally known in the fields of space policy, development, and education. Prior to coming to the U.S. in 1978, he was director of research for Canada's largest philanthropic foundation. Since then he has worked as an independent consultant to government agencies, corporations, and non-profit organizations, as well as holding government and academic positions.

In August 1982 he was Chairman of Non-Governmental Organizations for the United Nations Conference on the Peaceful Uses of Outer Space (Unispace 82), held in Vienna, Austria. In March 1985 he was appointed by President Reagan as one of fifteen members of the National Commission on Space, mandated by Congress to prepare a fifty-year agenda for the United States in space. From 1986-88 he founded and chaired the nation's first multidisciplinary Department of Space Studies at the University of North Dakota. During the same period, he was founding Chairman of the International Space University and is currently on its Board of Governors. Positions held since 1989 include Visiting Research Scientist and Professor at the University of Central Florida; Director of Space Education, Research and Technology at Embry-Riddle Aeronautical University in Daytona Beach, Florida; and member of the Science and Engineering Education Council of the Universities Space Research Association. He has been active as an independent consultant since 1994.

Dr. Webb has been interviewed by national and international media, including CBS, ABC, NBC, CNN, McNeil-Lehrer on PBS, and local stations throughout the U.S.; also CBC (Canada); BBC and ITV (U.K.); Swedish State TV; ORT, Austria; and Japanese TV, radio, and newspapers. He holds a master's degree from McGill University and a Ph.D. in International and Development Education from the University of Pittsburgh.

James A. Vedda

Jim Vedda was a member of the founding faculty of the Department of Space Studies at the University of North Dakota in Grand Forks, where he taught in the multidisciplinary graduate program for six years. During that time, he served as department chair for a year and a half and as associate director of the North Dakota Space Grant Program for two years. Prior to that, he was assistant to the Chairman of Non-Governmental Organizations at the United Nations Conference on the Peaceful Uses of Outer Space (Unispace 82), held in Vienna, Austria in August 1982. He also has held space-related positions in journalism and consulting.

Dr. Vedda is a frequent contributor to the trade newspaper *Space News* and other publications and has appeared as an expert commentator on CNN and on local television stations. He has given presentations to numerous groups on a variety of civil, commercial, and military space topics. He holds a master's degree in science and technology policy from George Washington University and a Ph.D. in political science from the University of Florida.

Introduction

Future historians who study the latter half of the 20th century will undoubtedly see the emergence of spaceflight as the most unique and far-reaching development of the period. The exploration and utilization of space for the betterment of humankind went from imagination to reality in a remarkably short time. In the quarter century since the last Apollo crew visited the moon, we've sent probes to most of the planets in our solar system and made great strides in using various orbits for telecommunications, Earth observations, and scientific investigations. However, we've done almost nothing to take advantage of the virtually limitless energy and resources that space has to offer. Will future historians choose to focus on this deficiency rather than our successes?

For a variety of reasons, the space program has changed from a strategically important, high-priority national program commanding presidential attention, to a domestic jobs program with minor foreign policy implications. In part, this has happened because a majority of Americans don't perceive a link between space developments and their daily lives, either from direct applications of space technology or from spin-offs. This is particularly ironic today, when so much that we do is dependent on satellites: communications, entertainment, data transfers of various kinds, weather forecasting, and navigation. Individuals can acquire receiving dishes for their TVs and computers, position location devices for themselves and their vehicles, and soon, versatile global communications systems, all of which interact directly with satellites in orbit.

A recent report summarizing a decade and a half of surveys on public attitudes toward the space program estimated that about 10 percent of adults in the U.S. consider themselves "attentive" to space activities, while those who consider themselves "interested" constitute about another 22 percent. To some, one-third of the adult population may seem like a healthy amount of support. However, the extent to which this group can lead public opinion or influence decision-making is doubtful. The same study revealed that science and space literacy among the attentive and interested public is surprisingly poor, and literacy in the non-attentive public is even worse.

In some ways, this level of interest and knowledge is not surprising. Space activities cover a broad range of esoteric, technical disciplines. Societal benefits from space, though numerous and pervasive, are transparent to most consumers—they are taken for granted and their link to space technology is not perceived.

The American people need a greater awareness of the role that space development has played in their lives. Most importantly, they need to realize that the space adventure did not end with the Apollo moon landings. The greatest benefits—to the economy, to human health, to the environment, and to a host of other areas—still lie ahead.

The pages that follow provide a brief introduction to some scientific, technical, and political topics that hold the key to turning even more of our dreams into reality, in both the near-term and long-term. Sustained support, from policy-makers and the public, is the ingredient that can bring all of these ideas to fruition.

The Role of Congress in Humankind's Future in Space

The effort to explore and develop space will prove to be the most complex and far-reaching endeavor the human species has ever attempted. It will build momentum over many generations, each one facing and overcoming challenges that the previous one could hardly imagine. Political institutions must adapt to these continuous changes, and as much as possible, anticipate them.

When must this adaptation begin? How will it be achieved?

In some small ways, political adaptation to the next era in space has already begun. Legislation enacted since 1984 has centralized the licensing and regulation of commercial space launches in the Department of Transportation. Similar duties in support of satellite remote sensing have been assigned to the Commerce Department. The U.S. Customs Service has found itself compelled to rethink its import-export rules as they apply to payloads on space vehicles. Technology transfer restrictions are gradually being eased, and the U.S. is joining countries all over the world to eliminate barriers to trade in products and information.

All of this is a good start at promoting the coming space era, but much more needs to be done. Congress has an important role to play, and it involves more than simply increasing NASA's budget.

A recent survey conducted for the Council for Excellence in Government indicates that "promoting space exploration" is the only one of 16 tested items about which a plurality of Americans say the federal government has been very successful. History has taught us that government is most likely to achieve success when it undertakes the following actions:

- basic research and development
- creation of infrastructure
- early adoption of emerging products and services
- regulation

In the space arena, government has taken all of these actions, thus generating successes that are both real and perceived. However, government actions have faltered in consistency and timeliness. Participants in space efforts, particularly in the private sector, place a high value on stability. Policy reversals, roller-coaster support, and legislative remedies that come too late all discourage continuing involvement in the space enterprise.

What should Congress do now to enable the space visions of the coming decades?

- Support current proposals for a two-year authorization bill for NASA, and adopt a two-year appropriations bill as well. The multi-year character of NASA's programs will persist. As a result, civil space programs will be better managed, politically and technically, if they are handled in a long-term manner.

- Continue to remove unnecessary barriers to trade and innovation, including outdated laws and regulations that unintentionally hinder space development.

- Keep the space science program strong. It is unparalleled in the world, and space visions would be poorly served by abdicating this position.

- Complete the space station. Despite its developmental problems, it will be the best orbiting laboratory facility available for the next two or three decades. It could teach us much of what we need to know to proceed with the next steps.

- Send a clear signal to NASA that solving the problems of access to space should be the space agency's top engineering priority. The specific launch vehicle concept (single-stage-to-orbit, two-stage-to-orbit, etc.) is less important than obtaining the capability for cheap, reliable, frequent, flexible access to space.

- When setting space goals, remember that goals should involve the establishment of ongoing, beneficial capabilities. A goal is not merely the creation of a piece of hardware, nor is it the planting of flags and footprints on a planetary surface.

Implementation of visionary space goals hinges on more than just the steady progress of technology. At some point, we must consciously begin the journey and then doggedly persist for an extended period of time. If the 21st century is to see the fulfillment of the dreams, then the journey must begin now.

Setting National Space Goals

Recommendation: A multi-decade plan for doing valuable work in space using extraterrestrial resources.

With the exception of the telecommunications industry, non-aerospace interests have been slow to embrace space as a venue for commerce and research. This is not surprising considering the cost, risk, and long time-horizons involved. To date, the result is that space exploration and development is still dominated by government activity. But in the U.S., Europe, and around the world, government space programs have been unable (or unwilling) to match the level of resources they spend on space to the things they want to do in space—assuming, of course, that they know what those things are.

Launch facilities, tracking stations, and space stations are essential components of a space infrastructure that enable the achievement of goals. Space shuttle flights and other rocket launches can be steps toward a goal, or they can be merely a series of disjointed missions. Without goals, it's pointless to argue about whether humans or robots should be sent into space, because no decisions have been made about what work of lasting value either would do there. Without goals, space policy-makers get bogged down in heated arguments over costly but relatively minor details and lose sight of the big picture.

Once goals are set, planning can proceed on the transportation system and other space infrastructure components needed to achieve them. This is more difficult than it sounds, as demonstrated by the fact that long-term goals have been largely absent from the space program for over two decades. Today, setting goals has to mean more than saying we'll put a man on the Moon by the end of the decade, or a man on Mars by 2019, or any similar scenario. Nor can building a shuttle or a space station be considered a goal—these are merely milestones in the establishment of infrastructure to support a goal. And in times of fiscal constraint, it is critical to set goals that, unlike Apollo, will yield continuing operations of lasting benefit.

The problem with setting worthwhile goals in space development is that all of the really good ideas will take decades to achieve and will cost a fortune, discouraging private sector entities of all sizes from taking up the challenge. The expectations placed on space programs put them in a very different category than earlier human achievements like medieval cathedrals or Egyptian pyramids. Those ancient projects were expected to take a lifetime or more to complete, whereas today's political and economic environment calls for much quicker results. Such an environment cannot produce valid long-range goals for the space effort. The exploration and development of space is different from anything in human experience. It's more difficult, more time consuming, more costly, and potentially more rewarding than any historical model we might use for comparison.

Worthwhile, long-range space goals often resemble popular science fiction, but this should not be allowed to hinder their credibility in political and technical circles. Here is a sequence of goals involving several decades of effort:

1. Build, maintain, upgrade, and recycle nearly all space hardware (e.g., satellites, science probes, space stations) at facilities in space, emphasizing the use of lunar materials. The extensive human and machine infrastructure this would require is staggering by today's standards. But once in place, the benefits include substantial savings in launch costs, removal of size limitations for multipurpose platforms, longer lifetimes for space assets, the creation of a "used satellite" market, better control of the space debris problem, and fantastic opportunities for scientific research of all kinds.

2. Given the infrastructure required for the above goal, projects having more direct benefits on Earth are possible. The next goal could be substantially reduced dependence on fossil fuels through the use of energy sources from space. This could take the form of very large orbiting solar arrays that would collect the sun's energy and beam it down to receiving stations on Earth, each one delivering many times the power of the largest terrestrial generating stations. Proponents of fusion power present an alternative they claim is even better: collect the isotope helium-3 from lunar soil (where it is believed to be abundant, unlike on Earth) to fuel terrestrial fusion reactors. Either way, reducing dependence on fossil fuels, while still fulfilling energy needs, will be good for Earth's economy and even better for its environment.

3. If we want to preserve the Earth and take advantage of the limitless material and energy resources of space, the next step is to move heavy industry off the planet. It may sound like science fiction now, but in the long run it makes sense. Some industrial processes will actually work better in a microgravity environment and will benefit from free, easy access to hard vacuum and solar heating.

Much of the effort required by these goals will be undertaken by the private sector, as long as governments ensure a stable, supportive business environment. Note that none of these activities requires humans to travel farther than the Moon, although trips to Mars and nearby asteroids would be natural outgrowths of these endeavors.

Variations of the ideas outlined above have been propounded by space visionaries for decades, but so far no such goals are in place. Lacking guidance, the evolution of space development will be incremental and somewhat random. If a launch system or any large infrastructure component is built for its own sake, as a result of some convoluted interplay of political, bureaucratic, and technical forces, it becomes a goal in itself, doing a disservice to the greater community by overshadowing the larger, more productive goals. When that happens, paths are chosen by default, or none are chosen at all. As we develop space, it is critical to be on guard against pitfalls such as these.

Improving Access to Space

Recommendation: Make space access NASA's number one engineering challenge; encourage private-sector solutions and government/industry teaming.

Access. No single word better describes the number one concern of everyone interested in the exploration and development of space. Every participant in space activities—civil, commercial, or military—needs affordable, reliable, frequent, flexible access to space. Comparisons with Earth-based activities are illustrative of the problem.

Terrestrial shipping services deliver on a fairly predictable schedule, often book shipments on short notice, and hardly ever blow up the cargo. The same can't be said for space launch services. Delivery is frequently held up by technical glitches and bad weather, flights need to be booked two to four years in advance, and reliability rates for large launchers range from about 82% to 98%. Clearly, today's space transport services should not be measured by terrestrial standards, but if the grand plans of space visionaries and entrepreneurs are to be carried out, someday they will be.

To illustrate the point, imagine a trans-Atlantic shipping company that promises to deliver your extremely valuable cargo to its destination in two years—a boat would be specially built for it—with a 2% to 18% chance that your package would be destroyed along the way, and a freight charge of approximately 50% to 100% of the value of the cargo, plus insurance. At one time in seagoing history these may have been acceptable contract provisions, but today they are laughable. Similarly, today's launch services are inadequate for tomorrow's space exploration and development.

Space research suffers from problems similar to those of space cargo. Experiments may wait years for a chance at orbital flight. Assuming they make it to orbit safely, the experiments are severely limited in volume, power consumption, duration, and human attention. If an experiment fails for any reason, it will be months or years before it can be tried again. By contrast, scientists in terrestrial labs have direct access to their experiments on a daily basis. They get this by jumping into their cars each morning and driving to work, a comparatively inexpensive procedure. If their experiments fail, they can try again—tomorrow, not next year.

Poor access to space discourages scientists from pursuing this avenue. Talented researchers often prefer Earth-based projects that will yield results before their careers have ended, and at a fraction of the cost. This is true even if they believe space-based research could ultimately provide superior results.

After four decades of effort, access to space remains a difficult challenge. This technical hurdle, particularly the cost factor, has demonstrated the slowest rate of improvement of all space technologies. Through NASA, the government retains some of the responsibility for addressing this problem. The space agency has the expertise and facilities, and its mission includes applying these capabilities to socio-economic needs. The overwhelming influence that space access has on all other aspects of civil, commercial, and military space efforts would indicate that this should be NASA's top engineering priority.

The private sector also has the technical capability to contribute to solutions. And given proper motivation and some relief from anti-trust laws, industry can apply adequate resources to an effort of this magnitude. For example, construction of the Alaska Pipeline, a project of similar magnitude, cost $8 billion (in 1970s dollars) over four years. However, the returns that can be expected from investments in new launch infrastructure are less certain than those from the Alaska Pipeline. Corporate interests cannot be confident that they will get back what they've invested within a reasonable timeframe. Some form of government support is essential and appropriate.

NASA is taking this approach in the X-33 program. The space agency's resources are available to the project, but industry must put its own capital at risk. NASA and the Defense Department must become early customers for whatever operational vehicles emerge from this effort if it is to succeed.

For future space infrastructure projects, NASA must plan from the beginning for an appropriate home for the resulting operational systems. Although the agency will be an essential element in the initiation of these new systems, most of them will ultimately reside in the private sector.

Minimizing Risks in Reusable Launcher Development

Recommendation: Pursue two-stage as well as single-stage-to-orbit concepts for next-generation reusable launch vehicles.

NASA's Reusable Launch Vehicle (RLV) program is an effort to move to a new generation of launch capability. Over the past two decades, the space shuttle, a partially reusable vehicle, has taught us that bringing down costs and reducing turnaround time are greater challenges than originally anticipated. The RLV program is intended to meet the objectives that the shuttle left unfulfilled, and more.

Most experts agree that the long-term solution to the world's launch needs lies with completely reusable launch vehicles. However, the ultimate configuration of such a vehicle, and how we get there from here, are matters of great debate.

The RLV program is focused on development of the X-33, a one-third scale, suborbital proof-of-concept vehicle that would demonstrate the technologies required for an operational single-stage-to-orbit (SSTO) launcher. The X-33 project has an ambitious timetable, but what happens after its test series is complete is unclear. Even assuming complete success in meeting its objectives, there is no way to predict how much time and money it will take to build, test, and certify a full-scale operational version. Who will pay for it is also unknown.

There is also the risk that technical hurdles will prove more daunting than anticipated, as was the case 20 years ago with the shuttle. An SSTO will require breakthroughs in a number of technologies, particularly in propulsion and materials. And when designers begin work on the full-scale SSTO, they may find that available technologies limit payload size so severely that the new vehicle provides little or no cost savings compared to old launchers.

This is not to say that SSTO will never work, or that the X-33 shouldn't be pursued. It is NASA's job to take risks and push the technological envelope. But in an effort as important as creating the next generation of launchers, risks must be recognized and dealt with. Lessons learned from the shuttle urge us to acknowledge that there is more than one technological pathway to the solutions we seek.

The goal of the RLV program should be to enable the development of a launch system that is significantly cheaper, more reliable, and more flexible than what we have now. That doesn't necessarily imply the SSTO approach. NASA didn't specify SSTO in its request for proposals, but bidders perceived that the space agency would accept nothing less. That precluded consideration of a quicker, less risky, and possibly cheaper approach: two-stage-to-orbit (TSTO).

A completely reusable TSTO vehicle would require no new technologies, taking advantage of what we've learned during the past quarter-century in materials science, computer hardware and software, rocket propulsion, and space shuttle operations. It could be operational long before a comparable SSTO, and at a lower development cost. TSTO has the potential to deliver sufficient cost savings to justify the investment, and could fill the gap that may emerge between the retirement of the shuttle and the availability of an operational crew-rated SSTO. Additionally, the development and operation of a reusable TSTO will provide the learning experience needed to graduate to a fully capable SSTO as the technologies mature.

Ideally, the TSTO and SSTO approaches should be pursued side-by-side, since they will deal with mutually beneficial technologies. If a second RLV project is funded, as has been proposed, it should specify the TSTO approach so that both technological angles are investigated. This will prevent a repeat of mistakes made during the shuttle era that caused unnecessary expense and programmatic hardship.

Reusing the Space Shuttle's External Tanks

Recommendation: Begin storing used External Tanks in orbit and plan for future use in a variety of applications.

The External Tank (ET) is the only component of the shuttle launch vehicle that is discarded with each flight. Retrieving the used hulk from the ocean is not cost effective despite the ET's $35 million price tag. But what about taking it all the way to orbit and using it there?

For the past 20 years, proposals from a variety of sources have described in detail how ETs can be used for many valuable tasks if they are taken all the way into orbit by the shuttle. The payload penalty for the shuttle would be minimal. In fact, under current procedures the shuttle must expend some of its energy during ascent to position the ET for reentry.

An array of applications have been envisioned for the orbiting ET. It could be a platform for mounting instruments on its one-third-acre of surface area. It could be opened up and used as a hanger for assembly and repair of space hardware. Two tanks could be linked by a long tether and set to spin, creating a variable gravity research facility. And an ET could provide a large pressurized volume—nearly four times the volume of the old Skylab station if both the hydrogen and oxygen tanks are used. That volume could be used to scale-up or isolate processes originally developed on the space station.

Looking beyond Earth orbit, ETs could serve as unmanned cargo haulers to the Moon and Mars. They could be placed in orbit around their destination, or be maneuvered to a bumpy landing on the planetary surface. Alternatively, they could be outfitted as cycling spaceships that would continuously traverse a path linking Earth with Mars.

There is even value in breaking up ETs for scrap once they've been delivered to orbit. To launch a payload in the conventional manner equal to the ET's dry weight—about 68,000 pounds—would cost around $500 million.

A White House space policy released in 1988 stated that NASA should make ETs available at no charge, for a period of five years, to interested parties capable of maintaining and developing the asset on orbit. By the following year, the field of bidders had been narrowed to three, but none of these projects materialized within the five-year limit.

It's time to revisit policy toward alternative uses of the External Tank. In the near term, we should begin storing ETs in low Earth orbit for future use.

Resolving the Debate Over Human and Robotic Spaceflight

Recommendation: Set long-term objectives and priorities, then use logical rules-of-thumb to judge the appropriateness of human vs. robotic mission scenarios.

Since the beginning of the space age, there has been an ongoing family feud among the members of the space community. Supporters of humans-in-space programs are pitted against those who favor robotic space missions. From a policy-maker's point of view, however, the two approaches should be seen as complementary, not competitive. Each has its place, and the rules-of-thumb for choosing between them should be familiar to the space decision-maker.

- Mission cost is directly related to the mass of the spacecraft and the duration of the mission. Human-rated spacecraft are always more massive, while robotic spacecraft typically have much longer mission durations.
- Human missions should always depend on robotic precursor missions for destinations beyond Earth orbit.
- Automated probes should be used for journeys too lengthy for human travel using available technology (e.g., the outer planets) and destinations with environments too hostile for human operations using available technology (e.g., the surface of Venus).
- Robots tend to be very efficient at data gathering, but very poor at improvising in unanticipated circumstances.
- For the foreseeable future, missions aimed at conducting research and development, spacecraft assembly, or on-orbit repair are best performed by humans.
- By definition, life science missions require human presence.
- As missions and technologies evolve, humans and robots will undertake missions together, employing increasingly sophisticated interactions.

Disagreements over the relative value of human vs. robotic spaceflight are a result of two factors. The first is clashing professional cultures. Space scientists and engineers cannot be looked upon as a single, homogeneous group—the "rocket scientist" of popular myth. Each group has its own mode of operation and its own motivations. One thing they do share, however, is a thirst for challenging projects that advance the state of the art in their discipline and instill personal satisfaction. For the engineer, that thirst is sated by human spaceflight projects, but the scientist craves the rich data harvest of robotic investigations. NASA's roots in the Apollo era guaranteed the predominance of engineers in the space agency, and programmatic decisions have ensured higher budgets for human spaceflight programs. Space scientists naturally see this as a less-than-optimal situation.

The other factor fueling the disagreements is that oft-cited problem, lack of goals. If goals are clear and priorities are set, there is little mystery in the choice between human and robotic approaches. Do we wish to cultivate the resources and unique properties of space to expand social and economic horizons beyond our planet while making life better here on Earth? If so, then humans must live in space to perform research, build and maintain hardware, and investigate the unexpected things we undoubtedly will find. Do we wish to collect data on celestial bodies and phenomena as far as our instruments can reach, to discover as much as we can about the origins of ourselves and our universe? If so, then automated spacecraft of increasing sophistication can be sent to do the job, and humans need never go beyond low Earth orbit.

Do we wish to do some combination of the two? If so, we should look to the long term, set our priorities, and refer back to the rules-of-thumb listed above. Space policy-makers must rise above the counter-productive feud and, aware of its causes, act to steer its energies toward greater societal goals.

Enhancing Human Physiology Research in Space

Recommendation: Deploy a variable gravity research facility as an adjunct to the life sciences capabilities of the space station.

Studies of human physiology and the behavior of materials that are conducted on the space shuttle and the Russian Mir space station investigate what happens under conditions of microgravity, commonly referred to as zero-g. Similar investigations will be performed on the international space station. The results give us useful information about what happens when the powerful influence of gravity is removed, and other forces take on greater importance. The findings are often surprising, and they expand our knowledge of the subtle interactions of materials and the adaptations of biological systems.

While this knowledge is very important to the future of human spaceflight, there is more we need to learn that can't be studied on a microgravity facility. If people are to dwell on planetary surfaces for extended periods, we must know the effect that will have on their bodies. We already know that living in zero-g causes bones to lose calcium and become brittle, muscles to atrophy, fluids within the body to redistribute themselves, and the immune system to weaken. Will the same be true of extended stays on the moon, with one-sixth of Earth gravity? What about Mars, which has just over one-third of Earth gravity?

The gravity levels on the moon and Mars are obviously of great interest to us, since we can envision spending a lot of time there. But we also need to direct our attention to counteracting the deleterious effects of microgravity during long stays in orbit and long interplanetary journeys.

There are various ways to design a spacecraft to create artificial gravity by spinning all or part of it at some predetermined rate. Right now, we don't know what that rate should be. Designing the system to provide Earth-normal gravity is not necessarily the right answer.

Two factors determine the amount of artificial gravity created aboard a spinning spacecraft: the rate and the radius of the spin. For a given level of gravity, rate and radius have an inverse relationship—the faster the spin rate, the shorter the radius can be, and vice versa. If the spin rate is too fast, however, the crew may suffer from motion sickness or balancing problems. In any case, the engineering problems presented by a large, spinning spacecraft would be reduced by choosing a gravity level something less than Earth's. We need to discover the lowest gravity level that will eliminate the adverse effects we've observed under microgravity conditions.

A variable gravity research facility in orbit could run a series of studies that would tell us how well we can function on the moon and Mars, and determine the lowest acceptable gravity level for preventing the debilitating effects of microgravity. Such a research facility would likely be based on tethers rather than a large, rigid framework. Two habitable modules, or one module and a counterweight, would be connected by a tether and spun up to the desired speed, twirling the configuration around its center of mass. The length of the tether could be adjusted, as could the rate of the spin. In this way, a variety of gravity levels could be tested with human crews on board, and the results compared. Meanwhile, the human test subjects could run materials experiments that duplicate those being done on the international space station, and those results also would be compared.

The work of the variable gravity research facility would complement that of the international space station in many ways. If desired, the two space platforms could be placed near each other in the same orbit, simplifying access and enabling some operational commonality.

Establishing a Human Presence on Mars

Recommendation: Use the two small moons of Mars as stepping-stones to the planet and to the asteroid belt.

Mars seems far away when measured by the standards of present capabilities, but it is nonetheless irresistible to anyone curious about human destinations elsewhere in the solar system. A series of visits to Mars by robot scouts has shown us that the red planet has much to offer, and, remarkably, a few things that would seem familiar.

The familiar things include a solid, rocky surface; a day-night cycle almost identical in length to Earth's; four distinct seasons in each Martian year; polar ice caps at the north and south poles; and an atmosphere which, though thinner and colder than Earth's, has clouds, wind, and the ability to support some forms of mechanical flight.

Mars is smaller than Earth, but some of its geologic features are on a grand scale. The Valles Marineris is a canyon 3000 miles long and three times as deep as the Grand Canyon. The extinct volcanoes of the Tharsis region dwarf similar geologic features on Earth. Can the size of these features be accounted for by the lower gravity, only 38 percent of Earth's? Or are other forces at work?

The question of past or present life on Mars has intrigued human society for centuries, and recent findings of possible microfossils have renewed this interest. But the puzzle will remain unsolved until much more extensive investigation is done on Mars. The definitive evidence of past or present life may lie underground, where it is protected from ultraviolet radiation, or at sites other than the isolated spots visited by spacecraft.

These mysteries provide a hint of what can be learned only by venturing beyond Earth. Mars and the other bodies of the solar system serve as planetary laboratories, allowing us to ask global-scale questions without limiting ourselves to conditions on the one "sample" on which we live. How have impact cratering and volcanism affected other planetary surfaces compared to ours? How do global magnetic fields of different sizes and strengths interact with a planet's surroundings? What can we learn from the behavior of the atmospheres of Mars, Venus, and the gas giants? What can be determined about our shared origins, and the possibility that more than one place in the solar system has held the seeds of life?

Reasonably close and more hospitable than any other destination in the solar system, Mars is the gateway to the rest of our neighborhood. Its position makes it a particularly good stepping-stone to the asteroid belt—a storehouse of clues to the origin of the solar system and a bonanza of resources in the form of numerous small bodies unencumbered by strong gravity fields.

Mars gives us another bonus in our eventual quest for the asteroid belt. Its two small moons, Phobos and Deimos, may themselves be captured asteroids. Due to their low gravity, on-site investigation of these moons is much less energy intensive—requiring a smaller and therefore cheaper spacecraft and launcher—than a trip to the surface of Mars, and would yield valuable information for the future of Mars exploration and development. The Martian moons are likely to be rich in resources that will be useful for future space missions, initially in the form of oxygen, propellant, and shielding, and eventually as inputs to more advanced fabrication processes. We may find it sensible to land our first human sorties to the Martian system on Phobos and Deimos rather than on the planet's surface.

Human missions to Mars requiring some amount of "living off the land" have already been proposed. For example, these scenarios generally include extracting oxygen for propulsion from the mostly carbon dioxide atmosphere of Mars. We may not decide to use this technique on our first attempt, but ensuing visits undoubtedly will depend on locating, extracting, processing, and utilizing extraterrestrial resources, rather than on supplies from distant Earth. These capabilities, developed in our efforts to explore Mars, will be the first important steps toward functioning, and feeling at home, anywhere in our solar system.

Building an Interplanetary Infrastructure

Recommendation: Employ "cycling" spaceships to service ongoing operations on Mars.

Routine operation involving humans on Mars seems a daunting task, given the planet's tremendous distance from Earth. Depending on their relative positions in orbit around the sun, Earth and Mars are separated by a minimum of a few tens of millions of miles, and a maximum of over 200 million miles. Compare this to our moon, which maintains a constant distance of merely a quarter of a million miles.

Crewed spaceflights covering such distances must consider two important factors: trip times and energy requirements. The trip time to Mars would be several months each way, but this is quite acceptable if the crew is provided with sufficient safety, comfort, and productive activity. However, a spacecraft that can provide all these things must be quite large, presenting a formidable challenge in energy requirements—and therefore, cost.

Besides being massive, a spacecraft on a direct flight from Earth to Mars must accelerate to a Mars trajectory, decelerate when it reaches the planet, accelerate again when it leaves Mars, and decelerate again when it arrives at Earth. All of this adds up to an enormous consumption of fuel. Even today's relatively small unmanned probes, which only make the trip one way, carry a large percentage of their total mass in their fuel tanks.

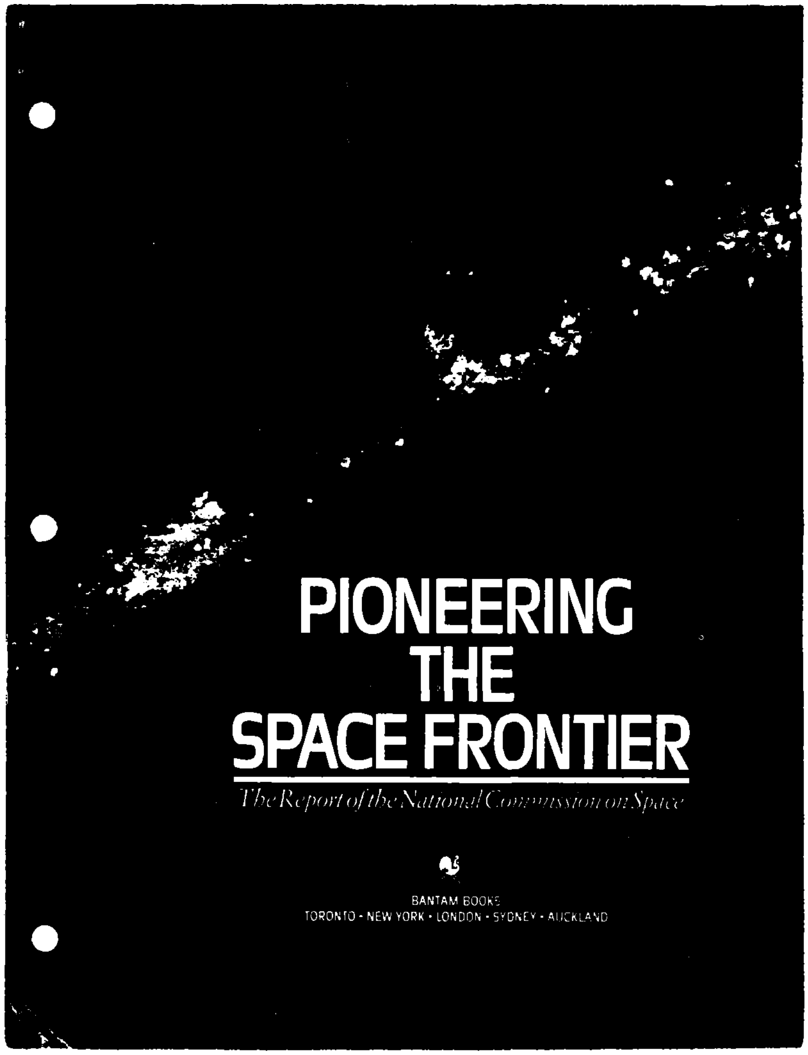
Initial missions to Mars will require this inefficient approach, but ongoing operations must find a better and cheaper way to make the transit. Cycling spaceships are a way to do this. They can become the ocean liners of space.

A cycling ship would be large enough to accommodate crew quarters, research facilities, food production, recycling, recreation, and sufficient radiation shielding for the deep space environment. It would be outfitted in Earth orbit, then launched on a trajectory that would place it in orbit around the sun. During each revolution around the sun, its path would intersect the orbits of Earth and Mars. This orbit could be maintained with a minimal amount of fuel consumption on each revolution.

The advantage of this method is that the massive spacecraft would only need to be accelerated once to place it in this useful orbit. It would not decelerate when it approaches either Mars or Earth. Instead, it would be met by much smaller, simpler ships that would bring crews and supplies headed between worlds. The small shuttlecraft would accelerate to match the velocity and direction of the cycler, dock with it, and stay aboard for the trip across the solar system. Upon reaching its destination, the small ship would detach and decelerate, using much less fuel than the fully outfitted interplanetary craft. Meanwhile, another small ship going in the other direction would accelerate to meet the cycler, and the process would repeat.

Two cycling spaceships in different Earth-Mars orbits would be needed to provide sufficient transit opportunities. A cycler will be a modular spacecraft that will be spun around its axis to provide varying levels of artificial gravity. On the trip from Earth to Mars, the gravity level initially can be set to duplicate what's normal on Earth, and then gradually be reduced to the level common on Mars (a little over one-third of Earth normal). The process can be reversed on the return leg, with the vehicle's spin rate gradually increasing to help passengers re-adjust themselves to Earth gravity.

Cycling spaceships would provide shipping lanes between planets. The concept can be extended to other planets besides Mars, although the red planet is the most likely first candidate due to its relative proximity, useful characteristics, and position as the gateway to the asteroid belt.


PIONEERING
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SPACE FRONTIER
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A NEW LONG-RANGE CIVILIAN SPACE PROGRAM

Program Thrusts
The National Commission on Space proposes a future-oriented civilian space agenda with three mutually-supportive thrusts:

- **Advancing our understanding of our planet, our Solar System, and the Universe;**
- **Exploring, prospecting, and settling the Solar System; and**
- **Stimulating space enterprises for the direct benefit of the people on Earth.**

We judge these three thrusts to be of comparable importance. They are described in Part I of our report: *Civilian Space Goals for 21st-Century America.*

To accomplish them economically, the Nation must make a long-range commitment to two additional thrusts:

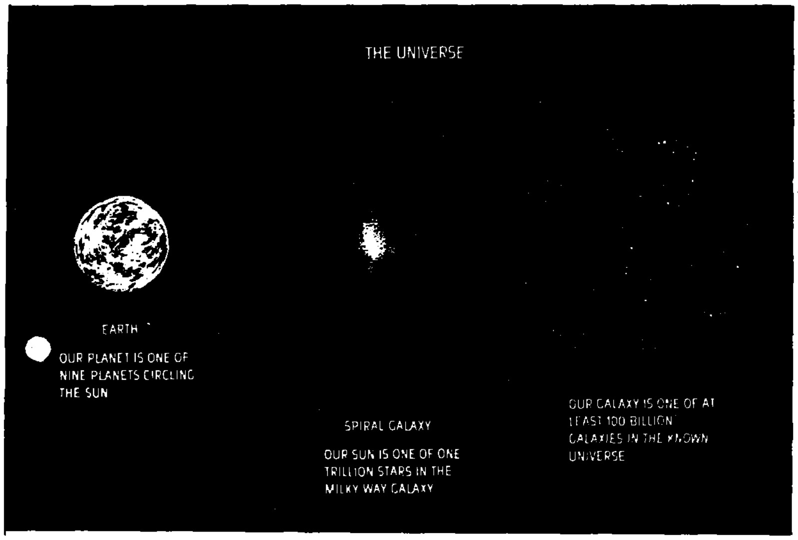
- **Advancing technology across a broad spectrum to assure timely availability of critical capabilities; and**
- **Creating and operating systems and institutions to provide low-cost access to the space frontier.**

These two thrusts are described in Part II of our report: *Low-Cost Access to the Solar System,* including *Building the Technology Base,* constructing a *Highway to Space,* and establishing a *Bridge between Worlds.*

A Logical Approach
To meet the challenge of the space frontier, the Commission proposes a sustained step-by-step program to open the inner Solar System for exploration, basic and applied research, resource development, and human operations. This program will require a creative partnership of Government, industry, and academia of the type that has proved highly productive in previous

national enterprises. U.S. leadership will be based upon a reliable, affordable transportation system and a network of outposts in space. This infrastructure will allow us to extend scientific exploration and to begin the economic development of the vast region stretching from Earth orbit outward to the surface of our Moon, to Mars and its moons, and to accessible asteroids. We can achieve our recommended program most economically and with minimum risk through a systematic program structured in accordance with the inner Solar System's natural characteristics: energy, distance, signal delay time, and availability of resources. These characteristics lead to a natural progression for future space activities within the inner Solar System.

- **Low Earth orbits** are those just beyond Earth's atmosphere and are therefore the easiest to reach from Earth. They provide both our nearest orbital view of Earth and our nearest clear window for observation of the Universe. Freedom from strong gravitational effects allows experiments impossible on Earth and facilitates construction of large structures of low mass. In this region, our mother planet provides a sheltering skirt of magnetic field that protects us from the radiation produced by solar flares.
- **Geostationary orbit,** 22,300 miles above Earth's equator, is the orbit in which spacecraft match Earth's 24-hour rotation and hold fixed longitudes. This valuable real estate is a tenth of the distance to the Moon and is the locale of today's entire civil communications satellite industry.
- **Lunar distance** is 240,000 miles. The Moon is our nearest nonterrestrial source of abundant materials. The energy required to bring materials from the Moon to high Earth orbit is less than a twentieth of that needed to lift an equal mass from Earth to such an orbit. Round-trip communication time for a television image traveling at the speed of light to arrive from lunar distance and for a responding command signal from Earth can be as low as three seconds. This short time may allow practical teleoperation of remote machines on the Moon by people on Earth.
- **Mars and the asteroids** are the nearest resource-rich bodies beyond our Moon. Because they are on the order of 1,000 times as far away, voyages to them require many months. Even at the speed of light, round-trip communication with them involves times of 10 to 40 minutes, so robotic machines on these Solar System bodies must be "smarter" than those on the Moon. However, certain distant objects with valuable resources can be reached with low energy expenditure, including the Martian moons Phobos and Deimos and some asteroids.
- **Work sites and energy.** We gain access to useful materials when we land on a moon or planet, but pay a price in propellants to descend to those surfaces. There we also lose full-time solar energy, which is valuable for industrial processing, and lose microgravity, which is advantageous for building large space structures. Early industrial production in space may, therefore, be best achieved by transporting raw materials from the Moon to high orbit for processing and fabrication into finished products in robotic factories powered by continuous solar energy. As on Earth, the economics of mining, processing, transportation, fabrication, and point of utilization will determine the best locations for transportation hubs and industrial centers within the inner Solar System.



Principal Recommendations

Consistent with our proposed five basic thrusts and the logical approach outlined above, the major parts of our report that follow include a number of specific recommendations.

Advancing Science

We recommend an aggressive space science program with three major objectives: (1) understanding the structure and evolution of the Universe, our Galaxy, our Solar System, and planet Earth, including the emergence and spread of life; (2) applying this understanding to forecast future phenomena of critical significance to humanity; and (3) using the environment of spaceflight and the tools of space technology to study the basic properties of matter and life. We have reviewed the current plans of U.S. science advisory groups for orderly progress toward these goals in the several disciplines of science. We endorse these plans, and note that an exciting opportunity exists to integrate the research results from previously separate disciplines. In order to foster this integrated approach to research on fundamental questions in science, the Commission recommends:

A sustained program to understand the evolution of the Universe, through astronomical facilities of increasing power, precision, and sophistication at locations in more distant Earth orbits and at eventual locations on the Moon.

A study of the evolution of the Solar System by using samples returned from selected planets, moons, asteroids, and comets. With returned samples, we can use all of our sophisticated laboratory technologies to perform the analyses. The results will also contribute significantly to the future discovery and utilization of space resources.

A global study of planet Earth using both ground- and space-based instruments. The goal of the study is in-depth understanding of the processes that shape our planet's interior, oceans, atmosphere, and polar ice caps, with particular emphasis on phenomena which affect, or are affected by, life, and the means to forecast, quantitatively, such phenomena.

A study of the Sun and the vast region it influences, using remote sensing from Earth as well as interplanetary probes. We must seek to understand the generation of energy deep in the Sun, its transformation into radiations that affect Earth and planets as well as life, and its interaction with solar and planetary magnetic fields. The processes involved occur throughout all space, so our understanding will be broadly applicable.

A continuing program to search for evidence that life exists—or has existed—beyond Earth, by studying other bodies of the Solar System, by searching for planets circling other stars, and by searching for signals broadcast by intelligent life elsewhere in the Galaxy.

Provision of state-of-the-art facilities for laboratory experiments on the ground and on the Space Station to increase the returns from the Nation's investment in space science, with particular attention to computer modeling, data access, advanced graphics, and artificial intelligence software.

New research into the effects of different gravity levels on humans and other biological systems, as well as on processes in physics and chemistry. The planned space program and the extension proposed here provide both the opportunity and necessity to resolve fundamental questions and to solve pacing problems that depend on gravity. Particularly needed are long-duration studies of the reactions of humans and plants to the microgravity of free space, the one-sixth gravity of the Moon, and the one-third gravity of Mars.

Exploring, Prospecting, and Settling the Solar System

In addition to basic scientific research, we propose specific applied-science investigations to discover, study, and learn to use for human benefit the resources on the space frontier. These materials have special value because they do not have to be lifted from Earth and carried over a long supply line. As a natural consequence of these investigations, the future will see growing numbers of people working at Earth orbital, lunar, and, eventually, Martian bases, initiating the settlement of vast reaches of the inner Solar System.

Living in space will be practical even though for long-term good health, people and the food crops that support them require atmosphere, water, sunlight, protection from radiation, and probably some gravity. Technological advances will permit all of these requirements to be met in free space; food, oxygen, and water can be recycled within an artificial biosphere, shielding from cosmic and solar flare radiation can be provided by lunar soil transported from the Moon with little energy, and artificial gravity can be provided by rotation. In the event of illness or accident, we can return people to Earth from lunar distance within a few days. Thus, the Earth-Moon region is favored for initial industrial production and for testing prototype spaceships and life-support equipment for later voyages to Mars and its moons.

To support these activities the Commission recommends:

Continuing robotic prospector missions, using the techniques of remote sensing and of on-site measurements to discover and characterize usable materials on our Moon, Mars and its moons, and accessible asteroids. A very high priority should be given to discovering any resources that may be frozen near the lunar poles, to determining the potential water and hydrocarbon resources on the surfaces of Phobos, Deimos, and near-surface layers of Mars, and to charting and analyzing all of the asteroids that pass close to Earth.

Missions to obtain samples from selected sites on our Moon, Mars and its moons, and the most accessible asteroids. When prospector missions have identified the presence of valuable chemical elements, sample return missions will be needed to bring back enough material to characterize the minerals and initiate industrial process development based on the physical and chemical properties of the samples.

Robotic and human exploration and surveying of substantial areas and special features of the Moon and Mars. This effort will begin on the Moon with automated roving vehicles tele-operated from Earth, and on Mars with vehicles having substantial artificial intelligence. Robots will be followed by the first astronaut crews operating from lunar and Martian outposts and bases.

Human outposts and bases in the inner Solar System. On the space frontier, habitations with closed-ecology life-support systems and reliable power plants will be needed to support work crews and, eventually, their families for long-duration work. Maintenance of good health for people working on science, exploration, and enterprise in distant communities, some of them at less than Earth-normal gravity, requires more knowledge and the development of dependable new systems. The development of long-duration habitation in space, based upon local resources, is essential to the support of activities in all three of our primary areas: science, exploration, and enterprise.

Space Enterprise

Our proposals span the range from involving private enterprise more heavily in post-shuttle space transportation to the support of major new industries. We propose that NASA should have a role in encouraging new space enterprises through technological development and demonstration analogous to its traditional successful support of the private sector in aeronautical research. It is imperative that the private sector be much more heavily involved in defining the nature and specifications of future launch vehicles. This will help ensure the adoption of commercial practices that will reduce operating costs and make it possible to transfer operation of these vehicles to the private sector. Future vehicles for cargo and passenger transport should be designed to be readily operable by the private sector after development is complete and routine operation is reached. To accomplish this the Commission recommends: **That wherever possible the private sector be given the task of providing specified services or products in space, and be free to determine the most cost-effective ways to satisfy those requirements, consistent with evolving Federal regulations.** We also recommend: **That NASA initiate research and development now on systems and processes for application beyond low Earth orbit.**

These systems should include tele-operated machines to repair and refuel satellites in high orbit, and the machines of robotic lunar pilot plants. Lunar resource utilization will depend on automated and tele-operated machines which are reliable and easy to use. This equipment must be developed through the pilot-plant stage for robotic plants capable of transforming lunar and other non-terrestrial raw materials into propellants, shielding materials, structural elements, and industrial raw materials.

Building the Technology Base

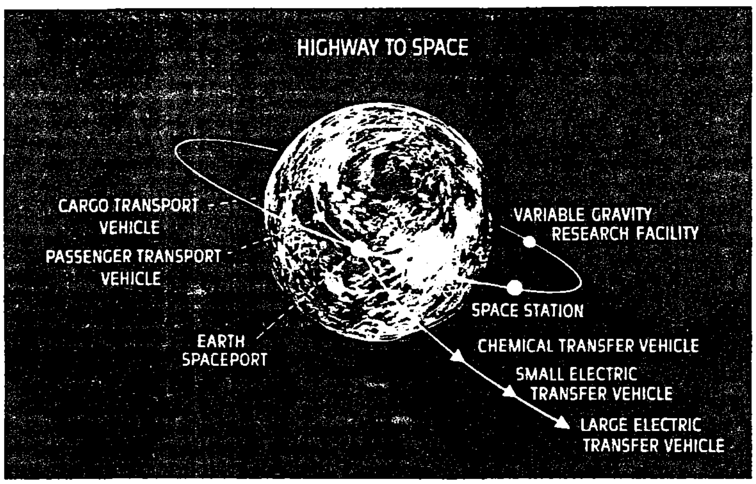
The United States must substantially increase its investment in its space technology base. We recommend: **A threefold growth in NASA's base technology budget** to increase this item from two percent to six percent of NASA's total budget. This growth will permit the necessary acceleration of work in many critical technical fields from space propulsion and robotic construction to high-performance materials, artificial intelligence, and the processing of non-terrestrial materials. We also recommend: **Special emphasis on intelligent autonomous systems.** Cargo trips beyond lunar distance will be made by unpiloted vehicles; the earliest roving vehicles on the Martian surface will be unpiloted; and processing plants for propellants from the materials on asteroids, Phobos, or Mars will run unattended. To support these complex, automated, remote operations, a new generation of robust, fault-tolerant, pattern-recognizing automata is needed. They must employ new computers, sensors, and diagnostic and maintenance equipment that can avoid accidents and repair failures. These systems must be capable of taking the same common-sense corrective actions that a human operator would take. These developments by NASA should also have broad application to 21st-century U.S. industry.

We recommend demonstration projects in seven critical technologies:

- **Flight research on aerospace plane propulsion and aerodynamics;**
- **Advanced rocket vehicles;**
- **Aerobraking for orbital transfer;**

- **Long-duration closed-ecosystems (including water, air, and food);**
- **Electric launch and propulsion systems;**
- **Nuclear-electric space power; and**
- **Space tethers and artificial gravity.**

These base technology and demonstration programs are discussed in detail in Part II of our report: *Building the Technology Base.*



Highway to Space

The two most significant contributions the U.S. Government can make to opening the space frontier are to ensure continuity of launch services and to reduce drastically transportation costs within the inner Solar System. The shuttle fleet will become obsolescent by the turn of the century. Reliable, economical launch vehicles will be needed to provide flexible, routine access to orbit for cargo and passengers at reduced costs. A complementary system is needed for low-cost transport from low Earth orbit to geostationary orbit and lunar distance. To reduce space operation costs as soon as possible, the Commission recommends that: **Three major space transport needs be met in the next 15 years; the three major transport systems requirements are:**

- **Cargo transport to low Earth orbit;**

- **Passenger transport to and from low Earth orbit; and**
- **Round-trip transfer beyond low Earth orbit.**

For cargo transport, we propose that a new vehicle be put into operation by the year 2000 with a goal of achieving operation costs of $200 per pound delivered into orbit.

For passenger transport, we see two competing developments for the follow-on to the shuttle: an advanced reusable rocket vehicle, or an airbreathing aerospace plane. These piloted vehicles could carry both passengers and compact cargo. Accordingly, we propose an intensive technology-base program for the next five years to provide critical engineering data on both systems so the Nation can make a sound selection by 1992. Key technologies include computational fluid dynamics, dual-fuel rocket propulsion, supersonic combustion ramjet engines, high-performance materials, structures, aerodynamics, thermal shielding, and launch automation.

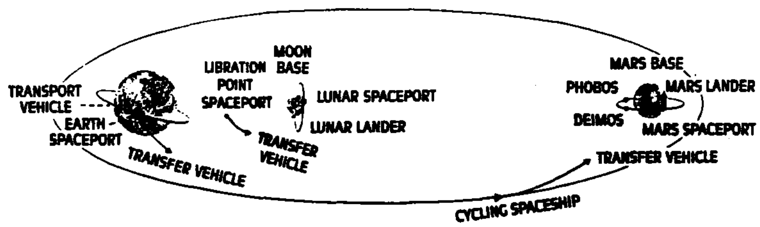
The airbreathing hypersonic propulsion has broad potential for a number of 21st-century applications, including intercontinental passenger transport, low-cost orbital transport, and a wide range of defense missions. **The Commission therefore supports a major national commitment to achieve early flight research with an experimental aerospace plane.** We also believe that in the next century the passenger transport system should be developed and operated privately for routine non-military operation between Earth and low Earth orbit.

For destinations beyond Earth orbit, a new transfer vehicle will be required. In the coming era of fully reusable Earth-to-orbit vehicles, the needs of Government and industry for the reliable emplacement of expensive satellites beyond low Earth orbit will require new space-based "workhorse" vehicles designed for flexibility through modular systems. Basic components should be capable of being ganged, or provided with extra tankage, for higher energy missions. They should be capable of transporting both cargo and people, be reusable, employ aerobraking, and be adapted to on-orbit servicing, maintenance, test, and repair. A transfer vehicle will be required to lift large payloads to geostationary orbit, to move payloads and crews to lunar orbit, to land payloads on the lunar surface, and to travel beyond the Earth-Moon system. Its Space Station base may be a critical pacing item. This vehicle should be designed for return to a low Earth orbit spaceport using aerobraking. The Commission recommends that: **The U.S. Space Station program be kept on schedule for an operational capability by 1994, without a crippling and expensive "stretch-out," and a space-based robotic transfer vehicle be developed to initiate a Bridge between Worlds.**

Bridge Between Worlds

Many of the systems needed for reaching outward to the planet Mars will be proven in the course of work in the Earth-Moon region. Others listed here are special to operations conducted at distances so remote from Earth that tele-operation and close mission support are not possible. To build the 21st-century Bridge Between Worlds that will open the Solar System, the Commission recommends:

BRIDGE BETWEEN WORLDS



Developing reliable high-performance electric propulsion systems, including mass-drivers and ion propulsion able to operate throughout the entire Solar System. Candidate technologies should be pursued vigorously to ensure that they will be ready when needed. Mass-driver reaction engines would be able to use as propellants raw materials from Earth's Moon, Phobos, Deimos, or asteroids. They, and other electric thrusters, would be able to run on solar or nuclear electric power.

Developing fully self-sustaining biospheres independent of Earth. For routine operation beyond the Moon, it is essential that life support be maintained using on-site materials, without reliance on long supply lines.

Establishing initial outposts and bases on the Moon and Mars that combine objectives, including life-support, science, exploration, prospecting, resource development, material processing, automated rocket fuel production, and robotic fabrication. Long-term exponential growth into eventual permanent settlements should be the overarching goal.

An Economical, Phased Approach

In considering the financial resources required to carry out our recommended agenda and future civilian space budget levels needed to meet our goals, the Commission considered the potential growth of the U.S. economy from a number of perspectives, as discussed in Part IV of our report: *21st-Century America*. Based on what we believe to be realistic growth assumptions, we are confident that the long-range agenda we recommend can be carried out within reasonable civilian space budgets. Figure 1 outlines our phased approach to achieve low-cost access to the Solar System. The Highway to Space starts with economical new cargo and passenger transport vehicles, adding a transfer vehicle for destinations beyond low Earth orbit. These three systems would become operational in conjunction with an orbital spaceport within 15 years. In the following 5 years, the Bridge Between Worlds would support initial robotic lunar surface operations, followed by a permanent outpost to support astronaut operations. In 10 more years the space bridge would be extended out to Mars for detailed robotic exploration followed by a Mars outpost for human activity. To achieve this the Commission recommends that: **The phased space transportation network outlined in Figure 1 be developed and placed in operation.** It starts with simple components, but evolves over time into a system of spaceports, bases, and connecting transportation systems that will open the space frontier for large-scale exploration, science, and the initiation of economic development. Resources will be utilized where they are found, to minimize the need for resources transported from Earth. This inner Solar System network will ensure continuing American leadership in space in the next century.

Implementing the Program

The hallmarks of this program are the technological advances needed for major cost-reduction and capability extension. Figure 2 depicts the growth of the U.S. Gross National

LOW-COST ACCESS TO THE INNER SOLAR SYSTEM

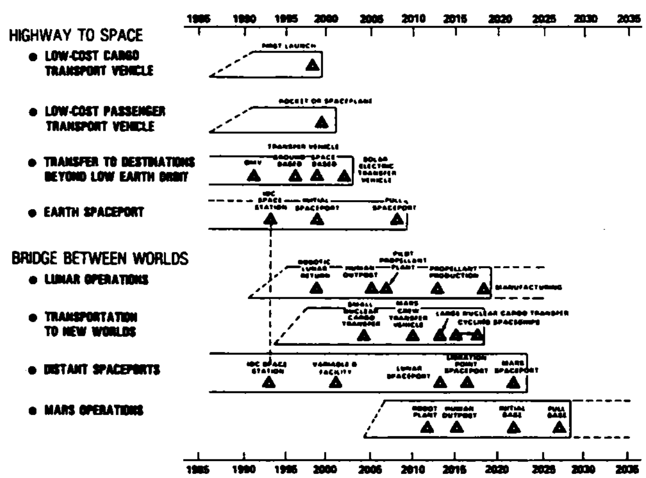


FIGURE 1

Product (GNP) for the past 25 years, and projects it forward for 50 years at an annual growth rate of 2.4 percent, as discussed in Part IV of our report. The estimated annual costs of the space advances that are outlined in Figure 1 are shown as an extension of the U.S. civilian space budgets of the past quarter century, assuming continuing international and commercial contributions to the program. Note that the percentage of the U.S. GNP invested in opening the space frontier would remain below one-half of the percentage spent on space during the peak Apollo years. We believe that these estimated levels of expenditure will prove to be affordable and reasonable in view of America's projected economic growth and the increasing significance of space development in the next century. We recognize, however, that this long-range program is a new challenge to the management of our Nation's space enterprise. For this reason we recommend that: **The Administration and the Congress continue to work together to set a new long-range direction and pace for America's civilian space program.** We sincerely hope that this Commission's report will contribute to a reexamination of and fresh approach to America's future in space. We see the need for longer-range vision, greater leadership, and more effective management of critical technological, financial, and institu-

COST OF PROPOSED US SPACE PROGRAM

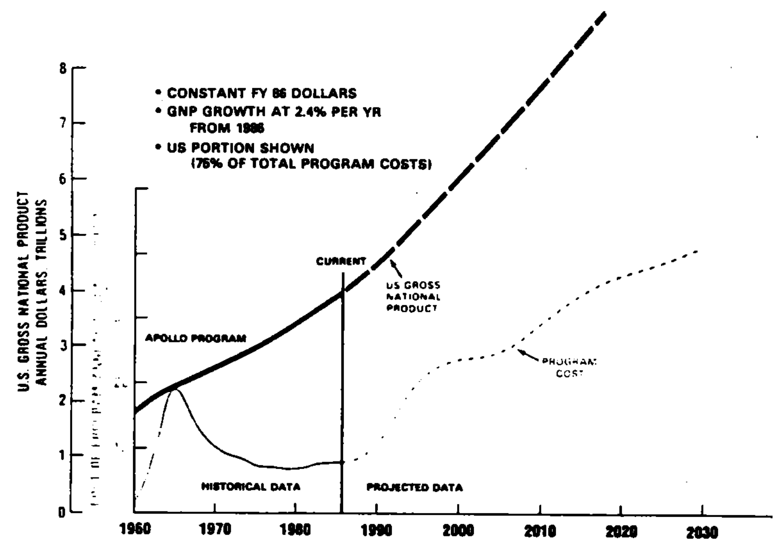


FIGURE 2

tional resources. This will also facilitate greater public understanding and participation, and more rewarding international partnerships.

The Commission's report has value only to the extent that its recommended space goals for 21st-century America are adopted and acted upon. If the decision is made to proceed along these lines, the detailed review, planning, and budget preparation should be carried out by NASA in consultation with NOAA and other agencies. The Commission therefore recommends that: **The President and the Congress direct the Administrator of NASA to review the Commission's findings and proposed space agenda, and by December 31, 1986, to recommend a long-range implementation plan, including a specific agenda for the next five years.**

Improved Oversight Through a Longer-Range Perspective

The President's Blue Ribbon Commission on Defense Management has recommended a number of reforms in defense systems acquisition that parallel our conclusions on improving the management of America's civilian space program. We recommend three specific changes similar to those proposed by the Packard Panel:

Twenty-year civilian space program and five-year budget planning to establish long-range goals and budgets for review and decision by the Administration and the Congress;

Multi-year procurements to replace year-by-year funding, with firm decisions that eliminate annual changes which have proven very costly to NASA and its contractors;

Two-year overall approval of civilian space budgets by the Office of Management and Budget and the appropriate Congressional committees to replace annual line-by-line auditing.

International Cooperation and Competition

This is discussed in detail in the section: *International Cooperation and Competition.* In proposing continuing American leadership on the space frontier, the Commission recommends that. **Vigorous steps be taken to attract other nations to work in partnership with us.** We must mobilize this planet's most creative minds to help us achieve our challenging goals. All of humankind will benefit from cooperation on the space frontier.

Twelve Technological Milestones in Space

The program we propose sets the stage for exciting achievements in pioneering the space frontier. A dozen challenging technological milestones would mark our progress:

- **Initial operation of a permanent Space Station;**
- **Initial operation of dramatically lower cost transport vehicles to and from low Earth orbit for cargo and passengers;**
- **Addition of modular transfer vehicles capable of moving cargoes and people from low Earth orbit to any destination in the inner Solar System;**

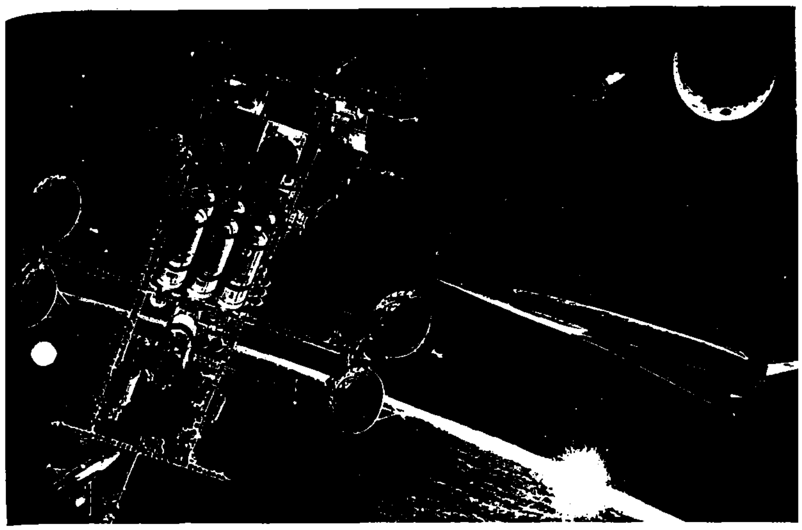
- **A spaceport in low Earth orbit;**
- **Operation of an initial lunar outpost and pilot production of rocket propellant;**
- **Initial operation of a nuclear electric vehicle for high-energy missions to the outer planets;**
- **First shipment of shielding mass from the Moon;**
- **Deployment of a Spaceport in lunar orbit to support expanding human operations on the Moon;**
- **Initial operation of an Earth-Mars transportation system for robotic precursor missions to Mars;**
- **First flight of a cycling spaceship to open continuing passenger transport between Earth orbit and Mars orbit;**
- **Human exploration and prospecting from astronaut outposts on Phobos, Deimos, and Mars; and**
- **Start-up of the first Martian resource development base to provide oxygen, water, food, construction materials, and rocket propellants.**

With these giant steps, America will lead a dynamic movement of humankind to new worlds in the 21st century.

BENEFITS

The new space program we propose for 21st-century America will return tangible benefits in three forms:

- **By "pulling-through" advances in science and technology** of critical importance to the Nation's future economic strength and national security;
- **By providing direct economic returns** from new space-based enterprises that capitalize upon broad, low-cost access to space; and
- **By opening new worlds on the space frontier,** with vast resources that can free humanity's aspirations from the limitations of our small planet of birth.



In the foreground is an aerospace plane and the Earth Spaceport. The Spaceport is receiving cargo from a cargo transport vehicle (lower left-hand corner). In the background, a two-stage transfer vehicle is returning to the Earth Spaceport from the Moon. (COURTESY ROBERT MCCALL)

"Pulling-Through" Technology

As we learned in World War II, government-academia-industry teams mobilized to accelerate advances in science and technology can build the foundations for new growth industries even though the original objectives were narrowly focused on military requirements. Wartime breakthroughs in jet propulsion, antibiotics, synthetic rubber, oil pipelines, nuclear energy, microwave radar, liquid-fueled rockets, radio guidance, electronic computers, and other systems led to America's high growth industries of the 1960s and 1970s in global jet transport, pharmaceuticals, synthetic materials, nuclear electric power, microwave communication, electronic computers, and many others. Technological advances from later Government programs made possible today's weather satellites, global marine communications, and the multibillion-dollar communications satellite industry that links together more than 100 nations on every continent. The space program has also initiated additional fledgling industries in remote sensing, direct broadcast, and navigation that appear likely to become future growth industries.

The program we recommend will motivate people, provide new standards of excellence, and stimulate many fields of science and technology, including those that we believe will be most critical to the economic growth of 21st century America. Specific examples include artificial intelligence, robotics, tele-operation, process automation, hypersonic flight, low-cost global and orbital transport, optical communication and data processing systems, ultra-high-strength and high-temperature materials, supercomputers, wireless power transmission, pollution-free vehicles (electric and hydrogen-oxygen fueled), orbital antenna farms, closed-ecology biosphere operation (which could revolutionize intensive agriculture)—and myriad others.

Return from Investment in Technology

In the last 50 years, Government-sponsored research and development created "enabling technologies" in aeronautics and in communications satellites. The needs of governmental agencies and of the public for new services attracted private capital to apply those technologies, leading to great new global industries. In the airmail contracts of the 1920s and 1930s, a public need for service played an additional vital role through the guarantee of markets to assist the growth of fledgling airline companies.

During the next 20 years, the Space Station may spark new industries by serving as a space laboratory for academic and industrial researchers. New processes of economic significance can be expected from applied materials and processes research in microgravity. Other new economic opportunities may come through laboratory environments isolated from Earth's biosphere, through the orbital global perspective for communications, navigation and observation of Earth, and through increased public access to space. Obtaining a return from new processes will require private investment in orbiting industrial parks established to provide common services to entrepreneurial companies carrying out independent operations in orbit.

New Space-Based Enterprises

In order to attract substantial private capital to build new space industries, the Government should create as early as possible the least expensive enabling technologies sufficient to open the energy and material resources of space. The private sector, especially its entrepreneurial part, is well situated and motivated to find the most rapid way to serve new markets. Companies are driven by the need to obtain returns on their investments, and financing is extremely difficult to obtain for high-risk ventures unless the returns occur quickly. This forces speed and concentration on specific opportunities.

We believe there will be such opportunities when the Highway to Space is extended via the Bridge between Worlds to high orbit and the Moon. The first products based upon materials found on the Moon include oxygen for rocket propellants and raw mass for shielding piloted orbital stations against cosmic and solar flare radiation. When the Highway to Space is extended to the Moon, an opportunity will be created to bring those products to Earth orbit at far less cost in energy than lifting them from Earth.

The transfer vehicle, capable of round-trip journeys from low orbit to the Moon and of piloted or remotely piloted operation, to which we give high priority in our recommendations, is the enabling technology needed to emplace experimental plants which could be operated by the private sector. When that second link in our space transport system is completed, the event will compare in significance to the driving of the Golden Spike in Utah more than a century ago that marked completion of the transcontinental railroad.

Private companies, driven by their need for rapid return on investment, could make use of the transfer vehicle to emplace economical pilot plants to provide lunar-derived shielding and oxygen. These plants would make strong use of robotics technology and would probably be tele-operated remotely from Earth. They would serve a highly valuable reinforcing role to the long-term space program by demonstrating soon the practical value of space resources. The Government could serve a vital role and reduce its own costs for space operations by committing to buy shielding and oxygen in Earth orbit.

We cannot foresee the ingenuity that companies, established or entrepreneurial, will bring to the building of new industries in the 21st century based upon the Highway to Space. Nor can we know the individuals whose names will rank with Douglas, Boeing, Sikorsky, and the other pioneers of the aeronautical industry. But looking back for analogies, we know that one of America's greatest heroes, Charles Lindbergh, practiced the skills of piloting in heavy weather, prior to his Atlantic crossing, by flying the U.S. mail.

New Worlds on the Space Frontier

The immediate benefits from advances in science and technology and from new economic enterprises in space are sufficient in our view to justify the civilian space agenda we propose. However, we believe that the longer-term benefits from the settling of new worlds and the economic development of the inner Solar System will prove even more rewarding to humanity. These returns are difficult to quantify. What was the true value of developing and settling North and South America, Australia, and New Zealand? Today more people speak English, Spanish, and Portuguese in the New World than in Europe, and they have built economies surpassing those of Europe. But the contributions to humanity from Columbus' "New World" are surely far beyond its material returns, impressive as they are. We believe that in removing terrestrial limits to human aspirations, the execution of our proposed space agenda for 21st-century America will prove of incalculable value to planet Earth and to the future of our species.

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FS-1997-01-011-HQ

Education

Preparing Today's Students and Educators for a High-Tech Tomorrow

NASA's vision for education is to promote the pursuit of educational excellence by involving "the educational community in our endeavors to inspire America's students, create learning opportunities, and enlighten inquisitive minds."

In carrying out its education programs, NASA is particularly cognizant of the powerful attraction the NASA mission holds for students and educators. The unique character of NASA's exploration, scientific, and technical activities has the ability to captivate the imagination and excitement of students and teachers, and to channel this into education endeavors that support the National Education Goals.

Major Programs

- **Teacher/Faculty Preparation and Enhancement Programs**—NASA uses its mission, facilities, human resources, and programs to provide exposure and experiences to teachers and faculty to support the enhancement of knowledge and skills, and to provide access to NASA information in science, mathematics, technology, and engineering
- **Curriculum Support and Dissemination**—NASA provides supplementary instructional materials and curricula in science, mathematics, engineering, and technology based on NASA's unique mission, and to support the development and augmentation of higher education curricula.
- **Support for Systemic Change Programs**—NASA supports local, state, regional, and national efforts to enhance the goals of the educational community through individual or collaborative efforts with a range of partners. Systemic change encompasses the process whereby an entire system is re-engineered toward achieving a new goal. NASA is committed to supporting systemic initiatives in the areas of science, mathematics, and technology education, and activities vary depending on the needs of the institution.
- **Student Support Programs**—NASA uses its mission, facilities, human resources, and programs to provide information, experiences, and research opportunities for K-12, undergraduate, and graduate students to support the enhancement of knowledge and skills in the areas of science, mathematics, engineering, and technology.
- **Educational Technology**—NASA uses its unique assets to provide products and services that facilitate the application of technology to enhance the educational process for formal education and lifelong learning.
- **Mission, Research and Development, and Operations**—NASA uses the talent and resources of the higher education community in programs that contribute to the development of new knowledge in support of the NASA mission.

Program Achievements

- In 1996, NASA reached more than 3 million elementary, secondary, and college students, teachers, and faculty through education programs and educational technology resources.
- More than 200,000 teachers participated in NASA education programs; 20,000 teachers worked with education specialists and NASA scientists in laboratories at NASA Field Centers.
- Of the students from the Summer High School Apprentice Research Program (SHARP), 99 percent graduated from high school and were accepted in colleges.
- NASA Spacelink, an interactive network system for educators, logged 1,363,000 total sessions in 1996. Of this total, 208,000 sessions averaging 20 minutes/session were logged for 1,800 registered educator accounts.
- The Center-based K-12 Internet Initiative, which is part of the High-Performance Computing and Communications program, provides demonstration projects and online systems dedicated to bringing NASA science to teachers and students in the classroom, using examples from NASA's unique missions. NASA, led by the Ames

Research Center, organizes various interactive on-line projects that connect classrooms with ongoing science and engineering work. In 1996, 25 World Wide Web sites were established, with more than 2,000 schools involved in K–12 aeronautics cooperative agreements.

- Fiscal Year (FY) 1996 marked the third year of the NASA Experimental Program to Stimulate Competitive Research program, with continued funding for the original six awardees. These six consortia, in their first 2.5 years of operation, produced 225 refereed papers and were awarded $62 million in successful proposals. The original six awardees were evaluated at the end of FY 1996 to determine their eligibility for an additional 2-year award. Five states were evaluated by a panel of NASA officials to be worthy of 2 additional years of funding. One state will receive at least 1 additional year, with recommendations for improvement. In addition, 14 proposals were received for the second round of awards, with four new states selected in late FY 1996: Kansas, Nebraska, Oklahoma, and South Carolina. This brings the current number of awardees to 10.

Current Activities

Examples of NASA's current education programs include:

- Teacher preparation programs such as Project NOVA disseminate nationally an undergraduate pre-service model based on standards and benchmarks for science, mathematics, and technology. Teacher enhancement programs provide opportunities for in-service teachers to update their backgrounds and skills in science, mathematics, and technology. For example, NASA Education Workshops for Elementary School Teachers and NASA Education Workshop for Mathematics, Science and Technology Teachers provides leadership opportunity for 250 outstanding teachers; and the Urban Community Enrichment Program provides more than 900 urban teachers greater exposure to new NASA knowledge. Using multiple formats, "Teaching from Space" develops products that are incorporated into enhancement activities, providing tools that can be applied in the classroom and disseminated through the Educator Resource Center Network.
- The Aerospace Education Services Program has been redirected to an emphasis on teacher enhancement, so that specialists are now directly involved in supporting state systemic reform by providing technical linkages to NASA research and development and education programs and services.
- The National Space Grant College and Fellowship Program continues to evolve as a national network of institutions with interests in aeronautics, Earth/space sciences and technology. Space Grant Consortia are present in every state, plus the District of Columbia and Puerto Rico, involving more than 550 institutions. The total disbursement of NASA space grant funds in 1996 was $14.6 million. The consortia more than matched this amount with $26 million from other Federal sources, educational institutions, state/local governments, and industry.
- The Space Science Student Involvement Program is another very effective program, managed in collaboration with the National Science Teachers Association, the National Council of Teachers of Mathematics, and the International Technology Education Association, that promotes literacy in science, mathematics, and technology among U.S. students in grades 3–12. In FY 1996, more than 1,500 teachers and 8,000 students participated in and entered contests that demonstrated the students' skills in science as well as art, graphics, and writing.
- The Graduate Student Researchers Program provides graduate fellowships nationwide to post-baccalaureate U.S. citizens to conduct thesis research. Awards are made to a graduate student for a maximum of 3 years. On an annual basis, NASA supports approximately 400 graduate students pursuing master's or doctorate degrees in areas compatible with NASA's programs in Earth/space science, aeronautics, and aerospace technology.
- The NASA Classroom of the Future continues to be the major component of the educational technology program. Its role is to translate NASA technologies and research results into learning tools, demonstrations, and teacher enhancement programs that support standards-based education reform.

Partnerships

- The presidents of the Astronaut Memorial Foundation, Challenger Center for Space Science Education, U.S. Space Camp, U.S. Space Foundation, Young Astronaut Council, and Space Center Houston have joined with NASA to form the Aerospace Education Alliance. This alliance seeks to leverage individual efforts in supporting the goal of U.S. students being first in the world in science, mathematics, and technology.
- NASA's Education Division held a workshop in late calendar year 1996, in partnership with the National Alliance of State Science and Math Coalitions, titled "Linking Leaders for Systemic Reform." This workshop brought together NASA principal investigators, education, science, and mathematics coalition leaders from the states of Ohio, Mississippi, and Colorado to focus on systemic change in those states.

NASA Spacelink

World Wide Web: http://www.nasa.gov
Gopher: spacelink.msfc.nasa.gov
Anoymous FTP: spacelink.msfc.nasa.gov
Telnet: spacelink.msfc.nasa.gov
TCP/IP address: 192.149.89.61

NASA Facts

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FS-1997-01-009-HQ

Life and Microgravity Sciences and Applications

Using the Space Environment to Improve Life on Earth

Life Sciences Programs

NASA's life sciences research investigates the role of gravity in shaping living systems. The resulting knowledge is used to ensure the health and safety of space crews and to improve the health and the quality of life of people on Earth.

Through ground-based and in-flight research, life sciences programs investigate the effects of microgravity on plants and animals. Ground-based investigations obtain baseline information, validate flight experiment procedures, and test experiment hardware. Flight research involves flying experiments on missions using the Space Shuttle and Russian space vehicles, such as the Bion satellite and Mir space station. Scientific investigations are carried out in:

Gravitational Biology and Ecology
- Cell and Molecular Biology
- Developmental Biology
- Plant Biology
- Global Monitoring and Disease Prediction

Biomedical Research
- Physiology and Countermeasures
- Behavior and Performance
- Environmental Health
- Radiation Health

Advanced Human Support Technology
- Advanced Life Support Technology
- Space Human Factors Engineering
- Environmental Monitoring and Control

Microgravity Science Programs

NASA's Microgravity Research program reveals important physical, chemical, and biological processes that are obscured by gravity on Earth. Frequently, the research allows scientists to provide superior measurements of fundamental physical and biological properties unattainable on Earth. These data can be used to validate or challenge scientific theories, or serve as the basis for developing new theories to explain unexpected discoveries. For many scientific disciplines, research in the space environment is a new realm of discovery, providing fundamental insights that can serve as the basis for new applications and technology.

- Biotechnology
- Combustion Science
- Gravitational Physics
- Fluid Physics
- Materials Science

A natural extension of traditional Earth-based laboratory science, NASA's program sets the international standard of excellence in space-based microgravity research. The research is evolving from the relatively short experiments possible during Shuttle flights to long-duration flights on orbiting platforms such as the Russian Mir space station and the International Space Station.

Aerospace Medicine Program

NASA's Aerospace Medicine program is focused on ensuring crew health in the human space flight program. Through the development of appropriate requirements for medical operations and medical research, the program supports several activities, including telemedicine, the operational monitoring of crews' health status, the development of longitudinal studies of astronaut health, and the development of new technologies in health care. These activities have been beneficial to the enhancement of life on Earth.

Space Product Development

The Space Product Development program provides the required access to NASA experiment facilities and offers access to space, utilizing the Shuttle middeck, SPACEHAB, and Wake Shield facilities. Such access is prohibitively expensive for most corporations or small businesses, especially at the high-risk, exploratory stages. This barrier to access the commercial use of space has greatly inhibited the commercial development of space-linked products or services. Through the cost-sharing partnerships among NASA, universities, and industry offered by the Space Product Development program, private enterprises of all sizes are able to afford the research most important to the development of space-linked commercial products and services.

Resulting Beneficial Commercial Products

NASA's life and microgravity research projects have generated a wide range of benefits and spinoff products:

- **Bioreactor**—NASA developed this device to keep human and other cells alive and healthy during space experiments. It is already helping cancer research on Earth by providing a better way to grow and study tumors.

- **Excimer Laser Angioplasty**—In treating blockage of coronary arteries, this system uses a "cool" laser that removes arterial deposits with extraordinary precision and without unnecessary damage to arterial walls. The device resulted from a NASA-sponsored program to measure gases in the Earth's atmosphere.

- **Combustion**—This is an important technique for establishing fuel-lean flames, vital to significant reduction in nitrogen oxide pollutants. Combustion has different properties in space, and NASA research offers new insights into this age-old tool of humanity.

- **Cool Suits**—The liquid cooling garment worn by astronauts has been adapted to help people born without sweat glands to eliminate excessive body heat. Some people with multiple sclerosis have found that the cool suit relieves their symptoms. In both cases, the cool suit technology enables them to lead much more normal lives.

- **Faster, Better Blood Analyzer**—NASA sponsored the development of this versatile, economical instrument for the rapid separation and identification of blood components in very small quantities to maintain the health and safety of crews during long stays in space. It is both a research instrument and a diagnostic tool, with many applications in medicine, forensic science, pathology, biochemistry, and other biological sciences. Capable of analyzing a range of fluid substances other than blood, it also is finding use in the food, agricultural, cosmetic, and pharmaceutical industries.

- **Implantable Medication Systems**—Surgically implanting this system in a diabetic's abdomen can enable insulin to be replenished continuously to a patient's body. The pumping mechanism was based on a design developed for the Mars Viking lander.

- **Remotely Programmable Pacemaker**—Doctors can reprogram and fine-tune a pacemaker without the risks involved in surgical procedures by using bi-directional telemetry. This two-way communications technology was originally developed by NASA to communicate between Earth-orbiting satellites and ground stations.

- **Fetal Monitoring**—NASA and the University of California at San Francisco are collaborating to apply medical sensor technology to save the lives of newborn children and reduce medical costs.

- **Mechanical Response Tissue Analyzer**—NASA, Stanford University, and a small business teamed to develop a device that can directly measure the stiffness of long human bones by measuring the response to vibration.

- **Telemedicine Instrumentation Pack (TIP)**—The TIP is a compact package of medical diagnostic hardware that is being developed to support medical operations activities on the International Space Station. This device, interfaced with a computer, can be used as a tool to aid in remote diagnosis. It has potential applications in disaster response.

- **Left Ventricular Assist Device (LVAD)**—This device is an axial flow pump that has incorporated technology similar to the Space Shuttle main engine turbo pumps. The LVAD provides supplemental blood flow to compensate for insufficient flow from the natural heart. Because the unit is extremely small and uses very little power, the LVAD will be beneficial to many patients with heart disease.

- **Internet-Based Telemedicine**—NASA is utilizing the Internet and Internet tools for videoconferencing to conduct telemedicine consultations remotely. The application of computer technology and inexpensive computer networks has many applications, including disaster preparedness, medical consultation, and distance learning.

- **Laser Eye Treatment**—Ophthalmologists may be able to trace the early symptoms of eye diseases and spot cataracts before they are severe enough to require surgery, thanks to a NASA-developed laser light scattering diagnostic probe. The instrument has already been used in experiments investigating cataracts during the early stages of formation. The instrument is nearly ready for clinical trials.

Future Research

During 1997, the life and microgravity sciences programs will fund approximately 1,462 principal and co-investigators and fly more than 55 science experiments.

Budget

The Fiscal Year 1997 budget for life and microgravity sciences is $243.7 million, a decrease of almost $60 million from 1996. To enhance its science and technology development activities in an era of level or declining budgets, NASA has established several cooperative ventures with external organizations and researchers, including other space agencies.

Partnerships

- **Industry**—Research results from microgravity experiments are used to enhance the nation's scientific, medical, and industrial base. NASA tissue culture research, for example, has given the medical community a powerful new tool to study how cells form tissue, both in space and on Earth.

- **Government**—Agreements with the National Institutes of Health have led to joint workshops on the value of growing protein crystals in space. Proteins are important, complex biochemicals that serve a variety of purposes in living organisms. Determining the molecular structure of proteins will lead to a greater understanding of how the organisms function. Knowledge of the structures also can help the pharmaceutical industry develop disease-fighting drugs. In addition, NASA is collaborating with the institutes on several projects involving cancer research, including a technology to improve digital mammography techniques.

- **Space Biomedical Center for Research and Training**—NASA's Aerospace Medicine program has sponsored the development of an educational relationship among NASA's Johnson Space Center, the Russian Ministry of Science and Technology Policy, the Institute of Medical and Biological Problems in Moscow, and Moscow State University. This relationship has resulted in the creation of the Space Biomedical Center for Research and Training at Moscow State University. The center is focused on areas of cooperation, such as education and training in aerospace medicine and telemedicine. In addition, the center was formally created after the June 1995 Gore-Chernomyrdin Commission.

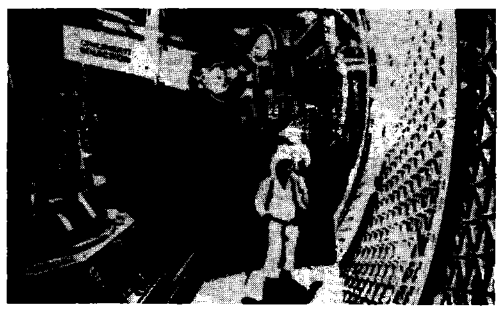
Agreements are in place with major universities in the area of aerospace medicine training and basic research in a variety of disciplines, such as telemedicine, the LVAD, and biotechnology.

Technology Opportunity

NASA's Operational Environment Team at Marshall Space Flight Center

NASA's Operational Environment Team (NOET) is looking for ways to share technology and information about environmental protection research with U.S. industry and other concerned agencies. NOET was organized in 1992 to ensure Federally mandated requirements of the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) are met to protect and restore our environment.

NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama, has been designated the lead Center for environmental replacement and propulsion technologies. In MSFC's Productivity Enhancement Complex, NASA is partnering with other Government agencies, industry, and academia, working to develop materials and manufacturing processes to meet Federal environmental protection standards. Along with environmental concerns, these partners are searching for ways to enhance the space program as well as foster technology for America's industries.



Potential Commercial Uses

The National need for environmental protection and cleanup is propelling industry and Government agencies to look for more effective and efficient ways to operate. Through NOET's extensive data base, information about environmentally protective hardware and replacement substances are available to other Government agencies, industry, and academia.

Benefits

NOET serves as a clearinghouse for NASA-wide environmental projects. American engineers will prevent duplication of effort as they tap into NOET's pool of information. By taking advantage of available NASA-developed technology and data, U.S. industries will save valuable time and money as they strive to meet Federal regulations designed to protect the environment.

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National Aeronautics and Space Administration

George C. Marshall Space Flight Center

The Technology

Replacement Technology

In MSFC's Productivity Enhancement Complex (PEC), scientists are developing replacement technology for adhesives, degreasers, dewaxers, fuels, paints and paint strippers, primers, insulation, flushing and cleaning agents, precision-cleaning materials, blowing agents, and brazing alloys. In the PEC, over 40 research cells are home to investigations for better materials processing, composites manufacturing, coatings and applications methods, and insulation improvements to protect and restore the environment.

In one PEC research cell, scientists use robotics to blast frozen carbon dioxide pellets onto a surface in an effort to find a replacement for harsh chemicals currently used for cleaning. Robotic waterblasting is being used in another cell to strip coatings from a surface without harming the environment.

National health, safety, and environmental standards have led to the development of new coatings. Alternative coatings are being tested to replace anticorrosion coatings for metal surfaces, weatherized coatings for foam thermal protection systems, and sealants that prevent water from getting into areas where it can collect and promote corrosion.

Propulsion Technology

NOET's propulsion technology team is working with other Government agencies and industries to develop cleaner versions of current fuels. Along with these propulsion-related technologies, this team is also conducting hybrid rocket studies, using both liquid and solid fuels.

Technology Transfer

More information about NOET's capabilities is available through MSFC's Technology Transfer Office. Representatives from this office can help you determine if NASA's technology can be adapted to meet the needs of your organization.

Contacts

Technology Transfer Office
Mail Code LA20
NASA/MSFC
Marshall Space Flight Center, AL 35812

Phone: 1-800-USA-NASA (862-6272)

Additional information about NASA's Technology Transfer Program and a Technology Transfer Agreement are available on the World-Wide Web:

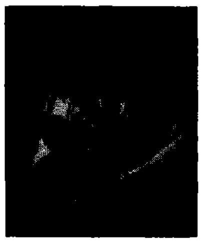
(http://techtran.msfc.nasa.gov)

Key Words

Environmental Protection
Technology Transfer

■ Technology Opportunity

Rapid Prototyping Laboratory at Marshall Space Flight Center



NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama, is using state-of-the-art equipment to produce prototypes for NASA and private industry. Although many major U.S. firms are experimenting with various aspects of rapid prototyping, MSFC is using its unique capabilities to help small businesses save both time and money on their "design-to-product" costs.

Potential Commercial Uses

Rapid prototyping technologies being developed for the space program have many uses in the commercial industry. When a concept is in the "selling" stage, a plastic model can be produced to serve as a visual aid. Wind tunnel models, used to provide performance tests, can be produced at lower costs than traditional methods.

Benefits

Startup costs of a new product line can be drastically reduced. Consequently, these savings to industry can be passed on to the consumer. For example, a wind tunnel model that once cost $40,000 and took months to produce can now be created for $400 or less—in just a few short weeks.

The Technology

Marshall's Rapid Prototyping Center has four machines designed for creating three-dimensional products from computer-aided drawings.

- A Fused Deposition Modeler is used to make investment master castings, particularly wind tunnel models. Wax or plastic material is fed from a spool, melted by a heated tip, and deposited layer-by-layer to build up a three-dimensional model. Future research with this device will include high-strength polymers and fiber-reinforced materials.

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National Aeronautics and
Space Administration
George C. Marshall Space Flight Center

- The Sanders Three-Dimensional Printer produces high-detail, high-surface-finished investment master castings. This machine has two inkjet heads—one deposits build material while the other deposits support material for overhangs. The current build material is an investment casting resin and the support material is a soluble wax that is easily dissolved from the finished part.

- A Stereolithography device produces wind tunnel models and other visual aids. Building from a computer-aided design file, this machine uses laser technology to build parts with photocurable resins. Models are created layer-by-layer with the directed laser, then post-cured in an ultraviolet oven. This technique is used mainly for concept modeling, but can also be used for investment casting.

- The Ballistic Particle Machine rapidly produces solid models, using an inkjet process. Micro-droplets of a low-strength wax material are fired from an inkjet head onto a surface, building up to a three-dimensional part. This technique is best suited for producing concept models.

Technology Transfer

More information about MSFC's Rapid Prototyping capabilities is available through Marshall's Technology Transfer Office. Representatives from this office can help you determine how this technology can best be used to help your company grow and prosper.

Contacts

Technology Transfer Office
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NASA/MSFC
Marshall Space Flight Center, AL 35812

Phone: 1-800-USA-NASA (872-6272)

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(http://techtran.msfc.nasa.gov)

Key Words

Rapid Prototyping	Investment Casting
Concept Models	Technology Transfer

■ Technology Opportunity

Composite Materials Manufacturing at Marshall Space Flight Center

NASA-developed technology to produce stronger, lighter-weight composite materials is available to U.S. industries through the Technology Transfer Office at Marshall Space Flight Center (MSFC) in Huntsville, Alabama. Although scientists and engineers at MSFC are working to develop better composite materials for use in the Reusable Launch Vehicle (RLV) program, the resulting technology has many other possible applications.

In MSFC's Productivity Enhancement Complex, automated composite fabrication systems can work precisely with many different types of materials, including glass, Kevlar, and carbon/graphite fibers. Engineers are involved in solid rocket motor case and nozzle technology; the development of advanced techniques for aerospace structures; thick composite structures; forming prototype parts for solid rocket boosters, external tank fairings, and space station equipment racks and pressure bottles.

Potential Commercial Uses

Composite materials are already being used to increase the strength of a product without increasing the overall weight. Many sporting goods manufacturers are taking advantage of lighter, stronger, more durable composite materials in the production of such items as tennis rackets, fishing rods, skis, boat hulls, and golf club shafts. This technology can also be applied to the commercial transportation industry.

Benefits

Strength: Carbon/graphite fibers, combined with resins, create stronger, lighter-weight materials.

Durability: When weight is not a major concern, Kevlar can be used in the place of carbon/graphite fibers to produce a durable composite material.

Economical: In situations where the material's strength and weight are not important, fiberglass is the most economical composite material to use.

Pub 8-537-2(03)

National Aeronautics and
Space Administration
George C. Marshall Space Flight Center

The Technology

Marshall's engineers use specialized machines and computer-aided drawings to produce high-strength, high-durability, low-cost composites.

The Filament Winding machine lays down ribbons of resin/fiber composite, building the material up layer-by-layer until the desired thickness and degree of strength have been reached. This four-axis vertical machine can produce both helical and polar patterns, with spherical parts up to two meters in diameter. Pressure vessels and similar symmetrically shaped items can be made with this machine.

A Pultrusion machine pulls resin through the die to shape it, creating long, continuous geometry tubes. This versatile machine can use carbon/graphite, Kevlar, or fiberglass, depending on the physical properties required of the finished composite item. This machine allows for rapid and economical manufacturing of parts.

The Tape Laying Machine in the Productivity Enhancement Complex has ten axes and three sensory systems. This three-dimensional automated tape laying machine will lay tape on flat or contoured surfaces with far greater control and precision than manual methods.

Marshall's Fiber Placement Machine is the first of its kind ever built. This machine was originally designed by MSFC and Cincinnati Milacron Corporation to make inlet ducts for the XF-22 jet fighter prototypes. Resin/fiber tapes can be deposited in patterns that can be narrowed or expanded, creating complex, geometrically shaped composite parts. Uses for this very sophisticated, computer-controlled robotic system are only beginning to be examined.

The Tape Wrapping machine at MSFC was designed to build solid rocket motor nozzles for the Space Shuttle. This machine has been adapted to produce nozzles that burn solid propellant/liquid oxidizer (hybrid) fuels and liquid fuels.

Technology Transfer

More information about MSFC's Composite Material Manufacturing capabilities is available through Marshall's Technology Transfer Office. Representatives from this office can help you determine how this technology can be used to help your company grow and prosper in today's competitive marketplace.

Contacts

Technology Transfer Office
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Additional information about NASA's Technology Transfer Program and a Technology Transfer Agreement are available on the World-Wide Web:

(http://ttectran.msfc.nasa.gov)

Key Words

Composite Materials
Materials Processing
Technology Transfer

■ Technology Opportunity

Tribology Tests and Evaluations at Marshall Space Flight Center

Tribology – the study of friction, lubrication, and wear of surfaces in relative motion – is the subject of many tests and evaluations being conducted at NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama. These scientists and engineers are searching for ways to provide more efficient, longer-lasting moving parts. NASA scientists are working with industry engineers to develop better bearing components for use in high-speed machinery.

Although Marshall's need to develop state-of-the-art tribological materials and components for NASA's on-going space program is spurring these technological advances, there are also industrial applications for this technology.

Potential Commercial Uses

High-speed, high-performance machinery is plagued by periodic maintenance and replacement of worn parts. Tribology investigations are important to manufacturers who provide aerospace components, air conditioning and refrigeration parts, and devices used in power plants with high-speed turbines.

Benefits

Many moving parts are often difficult and expensive to service or replace. Breakthroughs in the field of tribology will result in savings of both time and money for U.S. industry.

The Technology

Marshall's tribological test capabilities allow engineers to work in a hands-on environment, studying the fundamental concepts of tribology. MSFC scientists are able to recognize, understand, and solve problems with friction, lubrication, and wear as they conduct investigations ranging from the basic four-ball wear tests to high-speed cryogenic turbopump bearing tests.

Pub 5-537-2(05)

National Aeronautics and
Space Administration

George C. Marshall Space Flight Center

Hydrostatic Bearing Tests

The hydrostatic bearing test rig at MSFC is a fully functional device used to evaluate the performance of hydrostatic bearing designs. The current bearing design is for liquid hydrogen, nitrogen, or oxygen to be used as the working fluid. Other bearing designs can be developed and fitted into the tester for refrigerants and coolants. This tester, rated for 2000 pounds per square inch internal pressure and a speed rating of 80,000 revolutions per minute, can be used to evaluate hydrostatic bearing designs that might be used in cryogenic pumps, high-speed power turbines, jet engines, large refrigeration systems, and anywhere else the process fluid might be used as the fluid media.

Bearing and Seal Material Testing

MSFC's Bearing and Seal Material Tester is a high-performance diesel engine that drives rotor-bearing assemblies at speeds above 30,000 revolutions per minute.

An eight-station Rolling Contact Fatigue Machine is used to test the fatigue life of newly developed bearing materials and hard, thin-film coatings to identify the fatigue life of the bearing material.

A wide variety of materials, coatings, and lubricants are tested under differing conditions of friction and wear in Marshall's Falex Multispecimen Test Machine.

Lubricants are evaluated in a Shell Four-ball Wear Tester at MSFC to show the performance of different materials such as oils, greases, or dry film lubricants.

To test line contact with pure sliding, MSFC engineers use a Falex Pin and Vee Block Tester to measure the torque necessary to rotate the pin between two vee blocks.

MSFC's Traction Rig Tester simulates sliding-to-rolling contact ratio. This testing device is used to screen improved cryogenic bearing materials and lubricants.

A Long-Term Vacuum Lubrication Test System allows MSFC scientists and engineers to test a variety of commercially available lubricants for machinery that must function unattended for long periods of time.

The viscosity of oils and greases is tested in MSFC's Brookfield Viscometers. Rotating cylinder viscometers measure the drag torque of a cylinder submerged in a sample of lubricant material.

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Key Words

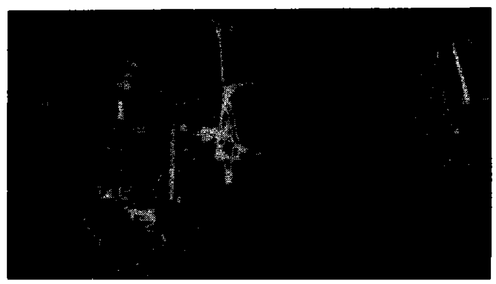
Tribology
Bearing and Seal Technology
Technology Transfer

■ Technology Opportunity

Avionics Systems Simulation at Marshall Space Flight Center

Marshall Space Flight Center (MSFC) has developed a unique avionics simulation capability by integrating several existing MSFC avionics testbeds. The NASA Federal Laboratory Review Task Force has declared this simulation system the best throughout the world for the aerospace community. The unique capability to unite Marshall's avionics simulation laboratories to perform extensive end-to-end avionics system testing in an environment not previously available makes this a "world class" facility.

MSFC's avionics simulation capability is fully operational and is being used to support several advanced initiatives such as the X-33 program, the international Space Station, and the Automatic Rendezvous and Capture program.



Potential Commercial Uses

In addition to the NASA programs supported by MSFC's avionics simulation capability, commercial applications include the automotive and trucking industries, flight simulation, space commercialization, and the commercial aircraft industry.

Benefits

Commercial industries can ground-test their hardware before subjecting it to hazardous and costly performance tests. For example, the automotive industry can test suspension hardware, saving time and money in the process. Flight simulation tests allow for pilot training and testing of hardware. The commercial aircraft industry can simulate automatic landing using one of the most advanced global positioning system simulation capabilities in the country.

The Technology

Recent developments in high speed, high bandwidth fiber-optic networks have allowed Marshall to "tie" three avionics laboratories together. These fiber-optic capabilities allow MSFC to test an avionics system in a mission environment that includes prelaunch operations, launch, orbital maneuvers, rendezvous, docking/berthing, and landing.

Pub 5-537-2(06)

National Aeronautics and Space Administration

George C. Marshall Space Flight Center

Marshall Avionics System Testbed (Launch Vehicle Development)

Three laboratories make up the Marshall Avionics System Testbed, bridging the gap between technology development and implementation.

The Vehicle Simulation Laboratory provides a tool for the demonstration of advanced vehicle avionics technologies such as flight computers, navigation systems, fault tolerant components, autonomous guidance, navigation, and control algorithms, automated software generation, and verification and validation products.

The Engine Simulation Laboratory consists of high fidelity real-time simulations of rocket engine systems with models of high frequency pumps, combustion devices, propellant lines, actuators, valves, and sensors.

The Actuator Test Laboratory, operated by the MSFC Propulsion Laboratory, is used in the design, development, and testing of actuation systems, ranging from small solenoids to large thrust vector control actuators.

Flight Robotics Laboratory (Orbital Operations, Rendevous, and Docking)

The Flight Robotics Laboratory (FRL) was developed to provide a single lab in which avionics and robotic hardware and software could be tested in a full 6-Degree of Freedom, closed-loop simulation. The facility is centered around a 44-foot by 86-foot precision air bearing floor – the largest of its kind. The Air Bearing Spacecraft Simulator, used on the air bearing floor, will hold a 400 pound payload and is capable of 6-Degree of Freedom motion. Overhead, the Dynamic Overhead Target Simulator is capable of holding a 1000 pound payload, with an 8-Degree of Freedom motion. A computer system allows the overhead payload to act as either a target or the rendezvous vehicle.

The FRL also has one of the most advanced global positioning simulation systems in the country. This device provides navigation data to the simulation vehicles, as if they were separate, moving vehicles in Earth orbit.

Contact Dynamics Simulation Laboratory (Docking Mechanisms)

The Contact Dynamics Simulation Laboratory (CDSL) allows engineers to simulate how a docking or berthing mechanism would behave in Earth orbit under a variety of conditions. Simulations in the CDSL reveal the stress a device will experience once in space through the use of force and torque data recorded on the system's SGI Challenge X/L simulation computer.

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Additional information about Avionics Systems Simulations, NASA's Technology Transfer Program, and a Technology Transfer Agreement are available on the World-Wide Web:

(http://techtran.msfc.nasa.gov) and (http://astrionics.msfc.gov/EB61/EB61.html)

Key Words

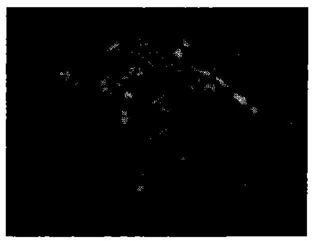
Avionics Systems Simulation
Robotics/Autonomous Systems
Technology Transfer

■ Technology Opportunity

Measuring Instrumentation Development and Evaluation at Marshall Space Flight Center

The Instrumentation Branch of the Instrumentation and Control Division at NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama, has the expertise and facilities to conduct research, development, evaluation, and selection of measuring instrumentation for a variety of applications. Scientists and engineers have developed instrumentation for propulsion system components for NASA's launch vehicles and for many of the flight experiments developed under the management of MSFC.

Marshall's Instrumentation Branch is available for developmental testing to evaluate sensors for pressure, temperature, vacuum, humidity, acceleration, vibration, heat flux, high-temperature strain, infrared to ultraviolet radiation, displacement, and gas analysis.



Potential Commercial Uses

In addition to the NASA programs supported by MSFC's astrionics laboratory, sensor development and testing has many commercial applications for industries that provide environmental monitoring devices, airline and automotive industries, the food industries, semiconductor industries, and fuel and chemical manufacturers.

Benefits

Commercial industries can benefit from the expertise and available testing facilities at MSFC. By taking advantage of the available resources within Marshall's Instrumentation Branch, manufacturers can better develop state-of-the-art sensors to measure the performance and health of a particular device or system, saving time and money on initial research and development.

The Technology

Scientists and engineers at MSFC use the facilities of the Instrumentation Branch to perform research, development, and evaluation of measuring sensors in support of Marshall's space flight programs.

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National Aeronautics and
Space Administration
George C. Marshall Space Flight Center

Optical Plume Anomaly Detection Engine Diagnostic Filtering System

Specialized research and development equipment at Marshall's Instrumentation Branch includes the Optical Plume Anomaly Detection system, which is used as a diagnostic tool and health monitor of liquid-fueled engines. Because of state-of-the-art technology in anomaly detection spectroscopy, Marshall scientists are able to discern trace amounts (parts per billion) of metals involved in the Space Shuttle's main engine plume. Once trace amounts are detected, the Optical Plume Anomaly Detection - Engine Diagnostic Filtering System extracts valid and useful information such as species quantification using preprocessing algorithms, neural networks, and spectroscopic/atomic models.

The goal of the Optical Plume Anomaly Detector is to provide early warning signals that imply imminent engine failure. The system, consisting of a spectrometer and a multichannel radiometer, obtains time-line data in the form of various metal atomic and molecular lines. Detection of certain traces indicates engine hardware deterioration.

In-Flight Leak Detection: A Hydrogen/Oxygen Leak-Imaging Sensor

MSFC scientists are working to develop and test an optical system to detect hydrogen or oxygen leaks during space flight. Due to size, weight, and availability of sensors, hydrogen and oxygen propellant leaks are difficult to detect in a space environment. Tracer gas techniques identify leaks during the initial checkout phase, but these techniques cannot identify leaks caused by cryogenic cool-down of joints. These techniques also cannot function when the spacecraft is fueled, on the launch pad, or in flight.

A confocal telescope has been constructed, allowing limited three-dimensional imaging. This imaging detector dramatically lowers the background fluorescence, which distorts conventional detection methods. A key part of this confocal telescope concept is that lower probe laser intensities (far below the threshold for igniting gases) can be used.

This technology is general in nature. It can be commercialized for applications such as hydrogen facility leak detection, forensic analysis, and automated surface inspection.

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Additional information about Avionics Systems Simulations, NASA's Technology Transfer Program, and a Technology Transfer Agreement are available on the World-Wide Web:

(http://techtran.msfc.nasa.gov) and (http://astrionics.msfc.nasa.gov)

Key Words

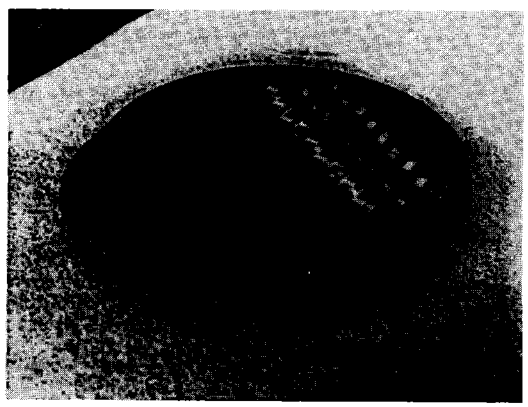
Astrionics/Measuring Instrumentation
Spectroscopy
Technology Transfer

■ Technology Opportunity

Diffractive Optics at Marshall Space Flight Center (MSFC)

Marshall Space Flight Center (MSFC) is the Center of Excellence for Space Optical Systems. Because of this, MSFC is NASA's lead center for identifying the technologies required to affordably produce the large space telescopes necessary for future missions. MSFC takes the lead in the process where NASA, other Government agencies, industry, and academia identify the technologies of the future, guided by the scientifically derived strategic plans. Another of the Center's responsibilities is to successfully infuse new technology into future missions.

MSFC and the U.S. Army MICOM Research, Development, and Engineering Center of Huntsville, Alabama, have established a co-located, joint micro-fabrication facility at the Redstone Arsenal where optical and direct-write electron beam lithography capabilities are in place. The major goal of this partnership effort is to foster fabrication research and development in the areas of diffractive optics and integrated optics. Additionally, the joint-housed facility provides technical support to projects in the development and application of advanced micro-optical systems, and serves as a focal point for technology transfer between industry, Government agencies, and university communities.



Potential Commercial Uses

Advancements in electro-optics have applications for improved law enforcement capabilities, high-speed measurement of engine components, non-invasive blood-flow rate monitoring, non-invasive imaging of internal organs, "over the fence" pollution monitoring, and many other uses in a wide variety of industry and commercial fields.

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National Aeronautics and Space Administration

George C. Marshall Space Flight Center

Benefits

Industry, other Government agencies, and academia have the potential to save a great deal of time and money as they take advantage of the expertise and capabilities at MSFC. The Center provides access to these facilities and equipment in an effort to ensure the U.S. stays on the cutting-edge of technology.

The Technology

The diffractive optics work being conducted at MSFC is a very promising technology for many space-based missions, including planetary discovery satellites. This technology could offer significant size and weight reductions, as well as potential increases in ruggedness and performance over standard optical systems. In addition, the diffractive optics technology enables many new and advanced micro-fabrication-based photonics technologies.

Where planetary discovery satellites are concerned, the area of space science may be most enabled by the introduction of diffractive optics. Diffractive optics could replace or hybridize conventional optical components to produce achromatic or athermalized optical systems. Many new and advanced micro-sensor technologies, such as those based on fiber optics, integrated optics, electro-optics, and micro-machining are extremely well suited for diffractive optics, anti-reflective coatings, polarizers, spectrometers, real-time signal processing, optical interconnects, telescope aberration correction, and communications.

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http://techtran.msfc.nasa.gov

Key Words

Diffractive Optics
Technology Transfer

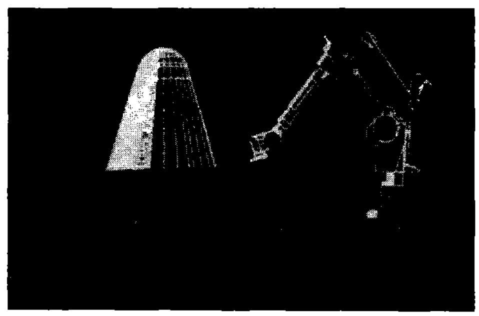
■ Technology Opportunity

Productivity Enhancement Complex at Marshall Space Flight Center (MSFC)

The Productivity Enhancement Complex (PEC) is operated by the Materials and Processes Laboratory at MSFC. Here, NASA and industry work together to develop new materials, processes, and assembly techniques.

The PEC is the focal point for cooperative research activities between MSFC and its contractors. These partnership efforts provide valuable benefits such as reduction of program costs, promotion and exchange of new ideas, and validation of new materials and processes.

The PEC can evolve along with new technologies. With more than 40 research cells, the PEC can accommodate a variety of activities such as creating or modifying computer programs for industrial robots used in welding processes, manufacturing space-age composite materials, vacuum plasma spray techniques, rapid prototyping, and cryogenic insulation development.



Potential Commercial Uses

NASA encourages collaboration efforts between NASA and industry to develop advanced manufacturing techniques. Manufacturing process improvements can be designed and tested using the unique capabilities of the PEC. Industries associated with the automotive, commercial airline, medical, and air conditioning and refrigeration have already taken advantage of the capabilities of the PEC.

Benefits

Enhancements in welding, rapid prototyping, insulation, composites, metallic coatings, and environmentally friendly cleaning techniques will result in savings of both time and money for U.S. industries. Startup costs, design, development, and testing can be done faster and cheaper by combining cutting-edge technology with current industry needs.

Pub 5-537-2(10)

National Aeronautics and Space Administration

George C. Marshall Space Flight Center

The Technology

Robotics are used to produce precise motion control, while allowing great flexibility of the path to be traced. Using commercially available industrial robots with advanced feedback sensors, engineers have the flexibility necessary to support testing of improved processes under a variety of conditions, simulating how the process might be applied to a manufacturer's facility. Applications include robotic waterblasting and welding.

The PEC's welding research cells are used for developing new welding techniques. NASA has developed methods for welding new aluminum-lithium alloys for lightweight tanks, high strength steel alloys for rocket motor cases, and high-nickel alloys for liquid fuel rocket engine applications. Friction stir welding and plasma arc welding techniques, as well as imaging, sensor and control mechanisms have also been developed.

Composites are generally less prone to corrosion and less sensitive to crack formation than metals, and their strength-to-weight ratio is significantly greater than conventional metals. The PEC contains precision automated composite fabrication systems that can work with many different materials, including glass, Kevlar, and carbon/graphite fibers. Process characterization, sensitivity studies, materials performance and weight saving studies, EPA/OSHA-compliance investigations, and advanced materials assessments are given high priority.

New coatings have resulted from enhanced performance requirements and national health, safety, and environmental interests. In compliance with EPA standards, alternatives are being developed that may replace anticorrosion coatings for metal surfaces and weatherized coatings. Evaluations are made for adhesion characteristics, corrosion-inhibiting capabilities, ease of application, and durability.

Insulation research cells are dedicated to improving performance and reducing the environmental impact of insulating material. They are also critical for qualifying both new foam formations and new commercial suppliers of flight materials. Activities include the development of lightweight, environmentally compatible insulating foams and the design and development of improved foam application systems.

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Additional information about the Productivity Enhancement Complex, NASA's Technology Transfer Program, and a Technology Transfer Agreement are available on the World-Wide Web:

http://techtran.msfc.nasa.gov

Key Words

Productivity	Insulation	Application Systems
Manufacturing	Coatings	Composites
Technology Transfer	Welding	Metal Processes
EPA	NOET	Foam

TECHNOLOGY TRANSFER OFFICE

Breast Biopsy System
LORAD Corporation, Danbury, Connecticut

Commercial Application

The creation of the LORAD Stereo Guide Breast Biopsy System stems from a NASA contract calling for the development of an advanced, thinned, super-sensitive silicon chip to convert light directly into electronic or digital images for the Hubble Space Telescope. The resulting state-of-the-art silicon chips, known as Charged Coupling Devices, are part of a digital camera system that "sees" breasts structure with x-ray vision.

Social/Economic Benefit

The LORAD Stereo Guide Breast Biopsy System is saving women time, pain, scarring, radiation exposure, and money because a biopsy can be performed under local anesthesia – using a needle instead of a scalpel. Around 90% of the 600,000 to 800,000 women who undergo biopsies each year are candidates for the LORAD system, potentially saving over $1 billion a year in medical costs. The LORAD system to date has benefited over 100,000 people, saving patients over $270 million.

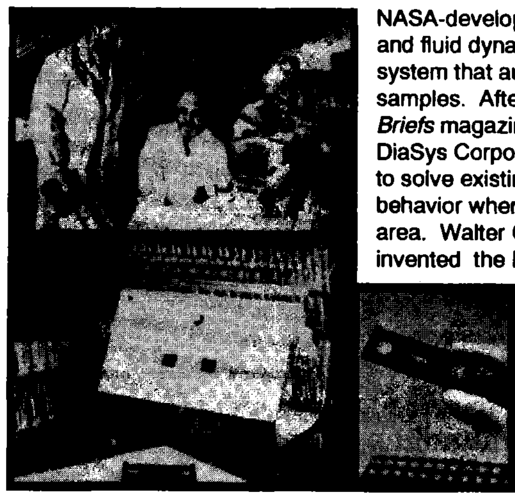
NASA Technology

NASA scientists developing the Hubble Space Telescope at the Marshall Space Flight Center and Goddard Space Flight Center recognized the need for a more advanced Charge Coupling Device that could be provided at a lower cost. Under contract to NASA, Scientific Imaging Technologies, Inc. of Beaverton, Oregon, manufactured the silicon chips, which are now part of the digital camera system of the LORAD Stereo Guide Breast Biopsy System.

1A-2426

NASA Technology and Medicine

Automated Urinalysis

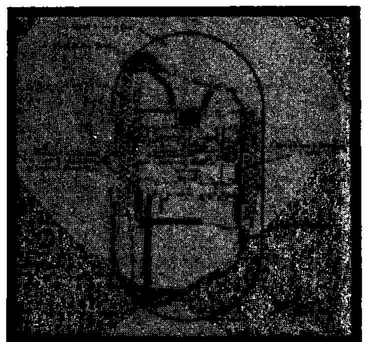


NASA-developed technology for hydrodynamic stability and fluid dynamics was used in the development of a system that automated the process of analyzing urine samples. After reviewing articles in NASA's *Tech Briefs* magazine, Todd M. DeMatteo, president of DiaSys Corporation, Waterbury, Connecticut, was able to solve existing problems involving unacceptable fluid behavior when the fluid was pumped into the viewing area. Walter Greenfield, the DiaSys engineer who invented the R/S 2000 system, discovered several articles in *Tech Briefs* that helped him design an aerodynamic optical slide assembly that could correctly deposit fluid into the viewing area. According to DiaSys officials, this urinalysis instrument speeds up, standardizes, automates, and makes safer the analysis of urine.

1A-2434

NASA Technology and Medicine

Temperature Capsule

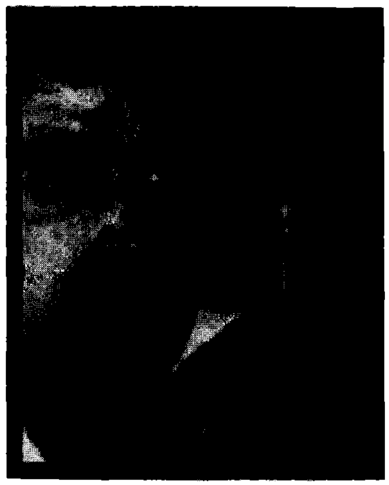


CorTemp is an ingestible mini-thermometer that can measure and relay body temperatures in post-surgery and critical care environments. CorTemp also allows physicians to monitor outpatients at home, work, or play. This tiny thermometer (measuring only three-fourths of an inch in length) incorporates a number of space technologies, such as telemetry and micro-miniaturized circuit, sensor, and battery technologies. Human Technologies, Inc., St. Petersburg, Florida, markets this temperature capsule, which makes its way through the digestive system, continuously monitoring temperature by means of a quartz crystal sensor that vibrates at a frequency that varies according to temperature. Other uses for the CorTemp ingestible capsule include research and treatment related to sleep disorders, sports medicine and physiology, metabolic diseases, tumor treatment by radiation, gerontology (aging), basal temperature analysis, and substance abuse.

1A-2443

NASA Technology and Medicine

Heart Research



NASA-developed technology is helping researchers at the University of Pittsburgh Medical School learn more about stress/strain relationships of the heart. One of the university's researchers, James F. Antaki, was looking for a way to implant "markers" inside the heart in order to visualize and track material points within the heart muscle. After reading an article in NASA Tech Briefs concerning available technology for making hollow microspheres, Antaki contacted NASA's Jet Propulsion Laboratory in Pasadena, California, who provided him with a complete set of NASA reports on every aspect of microencapsulation and directed him to contact Dr. Taylor Wang of Vanderbilt University in Nashville, Tennessee. These efforts resulted in the development of a marker that is being used to compute strains and associated stresses on the heart. This information is expected to lead to a better understanding of how the heart works and the changes that take place when the heart fails to function properly.

IA-2448

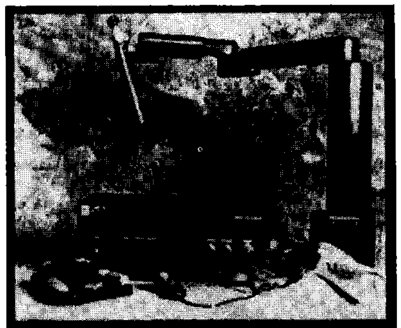
NASA Technology and Medicine

New Help for MS Patients

During the late 1960s, NASA developed a cool suit for astronauts to wear while working on the surface of the moon or during extravehicular activities outside spacecraft or the space station. But this cool suit technology has found even broader applications within the medical community. Life Support Systems, Inc., of Mountain View, California, has developed a cool suit that has had promising results for people who suffer from multiple sclerosis (MS). This disabling disease, which strikes men and women in the prime of their lives, affects the patient's thought processes, vision, dexterity, balance, and sensation. Research has shown that cooling the patient down by even one degree Fahrenheit improves the symptoms of MS. When worn for 30 to 40 minutes, the symptoms of MS can be dramatically improved for up to four hours. Although this cool suit is not a cure for MS or other such debilitating diseases, it offers a greater quality of life for thousands of people in our country today.

1A-2435

A Third Arm for the Surgeon

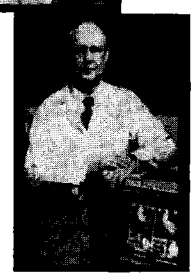


The Automated Endoscopic System for Optimal Positioning (AESOP) is a robotic arm that holds, moves, and positions instruments during minimally invasive surgery. AESOP, developed by Computer Motion, Inc., of Goleta, California, is the result of technology guidance as well as funding through the Small Business Innovation Research program. Dr. Yulun Wang, founder and president of Computer Motion, Inc., has incorporated NASA's technology for semiautonomous systems for assembling space structures and servicing spacecraft into this robotic arm that can be manipulated by the surgeon through the use of a foot pedal, allowing the surgeon to use both hands for the procedure. Using AESOP, the surgeon can perform minimally invasive operations such as gallbladder removal, hernia repair, gynecological surgery, orthopedic surgery, and neurosurgery about 20 percent faster than when using conventional methods. This means less time the patient must spend under anesthesia.

IA-243h

NASA Technology and Medicine

Heart Imaging System

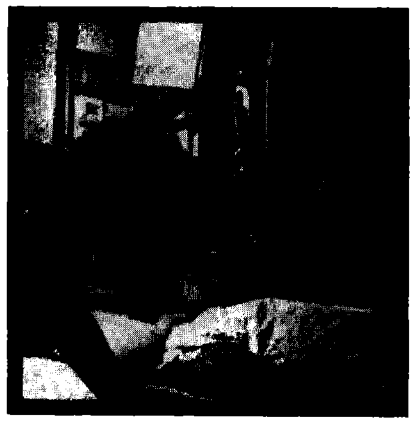


NASA-developed technology designed to test an astronaut's heart function in microgravity led to the development of the MultiWire Gamma Camera (MWGC). Marketed by Xenos Medical Systems of Houston, Texas, MWGC is a special camera that can image heart conditions six times faster than conventional devices. This camera has a number of features that distinguish it from conventional nuclear medicine cameras, including portability, high resolution, and exceptional imaging speed. Most importantly, the MWGC camera uses Ta-178 as the radioactive source. Because Ta-178 is an extremely short-lived isotope, the patient is subjected to it for only nine minutes – commonly used substances remain in the body for six to 72 hours. Because of the low radiation doses, pediatric patients can be studied with MWGC system.

1A-2440

NASA Technology and Medicine

Infrared Thermometer

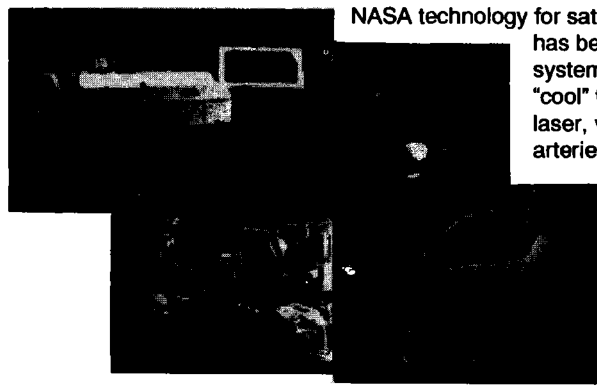


NASA's Technology Affiliates Program aided in the development of a new infrared thermometer that gives an almost instantaneous temperature reading. Diatek Corporation of San Diego, California, contacted NASA's Jet Propulsion Laboratory for help in developing an infrared sensor for their thermometer. With over 30 years of experience in remote measurement of star and planet temperatures, the Jet Propulsion Laboratory was able to provide expertise for the Diatek Model 7000 aural thermometer. This time-saving device permits rapid temperature readings for newborns, critically ill, or otherwise incapacitated patients.

IA-2447

NASA Technology and Medicine

Laser Angioplasty

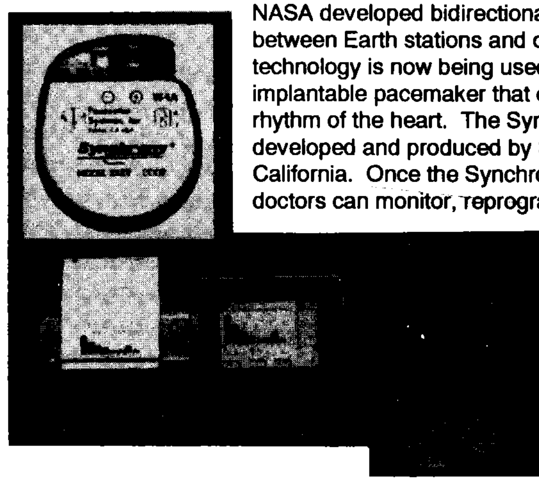


NASA technology for satellite-based atmospheric studies has been incorporated into a nonsurgical system that can unclog arteries. This "cool" type of laser, called an excimer laser, vaporizes fatty deposits that block arteries in the heart. Using video screens, the physician can monitor the procedure to guide a flexible catheter through an artery until it reaches the point of blockage. The doctor will then activate the laser beam to open the clogged artery.

1A-2456

NASA Technology and Medicine

Advanced Pacemaker



NASA developed bidirectional telemetry for communications between Earth stations and orbiting satellites. This technology is now being used in an advanced state-of-the-art implantable pacemaker that closely matches the natural rhythm of the heart. The Synchrony Pacemaker System was developed and produced by Siemen-Pacesetter, Inc., Sylmar, California. Once the Synchrony pacemaker is implanted, doctors can monitor, reprogram, and fine tune the system to best suit the patient's ever-changing needs. Using bi-directional telemetry, the physician can alter the rate of the pacemaker and then receive information about how the heart is reacting to those changes.

1A-2458

Mr. HASTERT. Thank you. The gentleman from Indiana, Mr. Souder.

Mr. SOUDER. Dr. Webb, I wanted to followup briefly on your technology fund question.

Mr. WEBB. Yes.

Mr. SOUDER. Are you viewing that as a space technology fund?

Mr. WEBB. No. I think it should be a technology fund generally. But I, of course, would naturally, if it came to it, say a space one first.

Mr. SOUDER. And how would you see this different, say, from the National Science Foundation, which gives grants?

Mr. WEBB. Well, the National Science Foundation does not give grants to particular programs over a long period of time. They make suggestions and study the programs and give funding when required, but not in what I'm talking about. I'm saying that Congress, when it decides to give funds to a program, should give the funds in total. That's what the Europeans do. That's what the Japanese do. Five year program: they get the funding guaranteed for 5 years.

Mr. SOUDER. Constitutionally, we don't have the right to bind the next Congress.

Mr. WEBB. I understand. If I may suggest that this be taken off-budget.

Mr. SOUDER. Right. That's why, for example, the National Endowment for the Arts, you can forward fund some grant type programs. The problem is that if a given Congress forward funds it, it means the whole budget item has to be hit that year, as opposed to being calculated over the 5 years.

Mr. WEBB. Unfortunately.

Mr. SOUDER. And that's also the danger. If it goes into a technology fund that isn't specified for space, it could—political pressures for high definition television or something could easily overwhelm. But it's an intriguing idea. Would you see this fund having any private sector matches?

Mr. WEBB. Yes. I think it would be very important that it have private sector matches. And of course, that will have a competitive issue involved in it, because we don't know what—a company will not match it if they don't think that they're going to get a contract. That just makes things very difficult.

Mr. SOUDER. In addition to contracts, would you have some sort of early rights to certain patents or access?

Mr. WEBB. Absolutely. It would have to. I think the Stevenson-Wydler Act—very nearly passed—and I think it was 1981—went into a lot of this in great detail. And I think it might be useful to review that act as a possible model.

Mr. SOUDER. Could you see that getting into solar energy questions, too?

Mr. WEBB. Indeed. I think that everything we've heard today in Dr. Glaser's and Dr. Criswell's proposals are very necessary things. And they were reviewed. Dr. Glaser's was reviewed particularly by the National Academy of Sciences, back in 1978. But since then we've done nothing with it. It is a great tragedy, because what is going to happen is the Japanese—in fact, Dr. Glaser would probably tell you he's been spending most of his time in the past 10 years in Japan, because they're the only ones that are saying to him, "Come on, Dr. Glaser. Tell us how to do this and we will control the electricity throughout the world." An important thing.

Mr. SOUDER. That segues into my next question. There's really two parts to this. Dr. Berendzen mentioned this at least in his written testimony. The question of what you just said of the Japanese dominating the energy question. But you alluded to the Chinese. In the international agreements on peaceful uses of space for non-dominance of certain categories. Is China a signatory to any of this?

Mr. WEBB. No. The People's Republic was not, that I know of.

Mr. SOUDER. What about North Korea, Iran or Iraq?

Mr. WEBB. I don't think so. We have an expert in international law right in the audience. Maybe they would know.

Mr. BERENDZEN. To the best of my knowledge they are not.

Mr. SOUDER. Because one of the problems here is that——

Mr. WEBB. They are not.

Mr. SOUDER. One of the problems here is that if only nations that are friends sign the treaty, it's not quite as far-reaching as if we had those who may, in fact, be competitors. Do you see—could you followup, Dr. Glaser, with the Japanese question just a bit, and do you see any willingness out of them to do joint efforts if it was pursued? Or is some of this just so competitive that certain streams are going to be trying to dominate? In fact, that desire to dominate may, in fact, advance science.

Mr. GLASER. Let me just also talk about the Chinese. Because at the International Astronautical Federation Congress, which took place last year in Beijing, Chinese scientists from the Shanghai Space Power Institute gave a plenary lecture which was a laser lecture, and their conclusion was very simply stated: we want to work with others internationally, in making this come about. So I believe that it is a possibility for this country to enter into discussions with China. Because he did not say that as an individual.

He was saying this as Chinese policy. As far as the Japanese are concerned, my first contact with the Japanese was shortly after the oil shock of 1973. They have the greatest incentive as a nation to develop solar power satellites or lunar power satellites. I think that they have understood it. And if you look at what they have done, they have systematically done all the right steps on a small scale: very inexpensive. It's all published. You can get it from them. There's no secrecy about it. Also, it's organized by meeting.

They have developed a way of enveloping the industry people. This is an industrial project, not a space project. Space is part of it. And they have done some exceedingly important experiments. I'll just mention one or two. For example, they've flown an airplane which was held up by wireless power transmission. That was done as part of the international space year effort. They have done a rocket experiment which beamed 800 watts from a rocket to a satellite.

At minimal cost, this was done by the Institute of Space and Astronautical Science. Now, we have not even attempted to duplicate something like that. Can you imagine what it takes to do that? It's a very challenging thing they've done. And by the way, they're not the only ones who have done it. The Russians beamed from Space

Station Mir—somehow nobody followed that up—to a Swedish satellite. They had wireless power transmission from Mir to a Swedish satellite.

So if I can say that this is an internationally very top grade project. And whether it's at the beginning stages now, that's where we have to be. Because once they decide to do it in orbit, or eventually—and I fully agree it will have to be done eventually on the Moon—we will be behind the eight ball. Because these other nations take this very seriously. The conferences—I would invite you to attend the next conference in Montreal: SPS 1997, August 23—28. There are all the representatives of these nations that have been working on it. And I think the interest for people from Congress to at least listen to what they are saying.

Mr. SOUDER. Thank you very much.

Mr. HASTERT. Thank you. Dr. Weldon.

Dr. WELDON. I thank the chairman. I just want to followup with a couple of technical questions to Dr. Glaser and Dr. Criswell. The Earth is turning. And if you have a power base on the Moon transmitting power, do you have the ability to move the antennae on the Moon and keep that receiver on Earth always on track, or is that the function of the satellites. I'm just a little confused how this would all work with everything moving: the Moon orbiting the Earth, the Earth spinning underneath it constantly. You said the technology is all there? Is that correct?

Mr. CRISWELL. Yes. The basic approach with a lunar system, the simplest system is you have the bases on the Moon, and they send power to a receiver on Earth when the receiver can see the Moon, which is half of the day. You could actually only use about 40 percent of the day. Then you could store excess power. Underground storage, hydro—many options.

That's an expensive way, even though it is cheaper than the way we do power now. The cheapest way, and I think the most elegant way is, that you would have in orbit around the Earth relay satellites. They would accept power from the Moon and then send out multiple beams down to receivers on Earth. These would be in high orbits, such as are associated with the Russian communication satellites, called high inclination orbits.

So it's a dynamic system in which beams will shift back and forth from the Moon to a satellite to the receiver where the power is needed.

Mr. WELDON. These are all microwave beams?

Mr. CRISWELL. These would be microwave. It's proposed for the industrial microwave band around 2.4 gigahertz, about 10 centimeter long waves.

Mr. WELDON. Is there any danger associated with those beams if they were to hit——

Mr. CRISWELL. The beams have to be kept at low intensity, so they would be safe. The way that these are normally modeled is, the beams will have an intensity of about 20 percent of sunlight. Now, those would go into industrially zoned areas. You would not want to walk around in them. You certainly could for periods of time, but that would not be good. Outside of that area, though, it would be a much lower intensity than beneath the safety guidelines.

Now, I think with the things that have happened since the 1980's, that it looks like the receivers on Earth can be much cheaper to build than were looked at in the early 1980's. What that means is, you can bring down the intensity of the beams below the levels that are now set or observed by IEEE and other standard organizations for continuous exposure of the general population. I don't think that's necessary to do. You're talking an industrial operation. And you would zone it.

Mr. GLASER. Could I, with your permission, just answer the safety question?

Mr. WELDON. Sure.

Mr. GLASER. This has been uppermost in the minds of all people who have worked on this concept. And there is a lot of domestic microwave use, like 300 million ovens. And we have—NASA, for example, has taken the sort of standard that, at the maximum—one quarter of sunlight—and at the edge of the receiving antennae would be about the same as if you stand 4 feet away from a microwave oven with a door closed.

We have done experiments on birds flying through the beam. This was done for the Environmental Protection Agency. So there's 13,000 papers dealing with microwave safety because it is widely used in industry and domestic uses. And there is a tremendous amount of information on all aspects. And we are committed in this kinds of a scheme to use all of the international standards which have been developed, which all countries adhere to, or at least, that's what they should do, to make sure that this is the safest energy production method.

Mr. WELDON. Thank the chairman.

Mr. HASTERT. Thank you. I have a couple questions. First of all, Dr. Criswell, the average American's consumption of energy is what, about?

Mr. CRISWELL. The average for the United States is about 11 kilowatts of thermal energy per person.

Mr. HASTERT. Of thermal energy.

Mr. CRISWELL. Yes.

Mr. HASTERT. So if you measured that in electricity, how much electricity would they use on the average?

Mr. CRISWELL. It depends on how you apply it. But as a rule of thumb, divide by a factor of three. You'd get 3 to 4 kilowatts.

Mr. HASTERT. So, the recommendation that we bring the rest of the world up to 2 or 3, you'd be coming close to the American average? I've been in China, an emerging nation, and they don't have enough electricity to do the things that they need to do as an industrial nation.

Mr. CRISWELL. That's right.

Mr. HASTERT. And of course, you get into Third World countries, and it's just not there. The average nuclear plant is perhaps—2,000 kilowatt-hours?

Mr. CRISWELL. Well, I tend to think of these things in gigowatts. Because—a billion watts.

Mr. HASTERT. Gigowatts.

Mr. CRISWELL. And a big nuclear installation—a collection of plants—will be about a gigowatt. I think the typical plant is half a gigowatt.

Mr. HASTERT. All right. Maybe 500——

Mr. CRISWELL. 500 megawatt.

Mr. HASTERT. Right. In my State, we have 12 nuclear plants. Two of them—in my area, two of them are going to be out of commission within a year, it looks like. As we start to cycle down those, you can actually deliver electricity in these low intensity beams? Can you deliver electricity in that type of numbers, quantity?

Mr. CRISWELL. Yes. You could supply the U.S. electric needs by using about 5 percent of the land area now associated with the generation and transmission of electric power. Including coal mines and railroads that are dedicated to it.

Mr. HASTERT. Dams and hydro.

Mr. CRISWELL. Now, I had the pleasure, over the last 5 years, to work with an economist at the University of Houston, Russell Thompson. Unfortunately, he died of cancer in January. One of the things I asked him to do was look at the proposition. Suppose the United States had stayed on the Moon with a small, permanent manned base after we finished Apollo. By 1980, that was the time that the studies of the solar power satellite systems were coming to a head, it was clear the technology was there to do that, but the costs were high.

And so, using the models that we've developed since then, we said, what would be the effect on the U.S. economy if we had instituted the lunar power program at that point in 1980 and built up to about 300 or 400 gigowatts of delivered power by the year 2000, and what would it have added—in his models, then, we could take the real economy and then we could look at how the economy was affected by this change in energy basis where the wholesale cost of electricity came out to about 3 cents a kilowatt-hour.

What we found was that you would have added by the year 2000 about $60 billion a year in direct economic benefit by this new source of energy. You would have had a multiplier of about a factor of three. So you would have been adding about four. You would have been adding a quarter of a trillion a year to the U.S. economy, not counting any add-on for export or sale of technology or export of energy.

Mr. HASTERT. I don't want to get a Buck Rogers-type scenario here. But if a country was able to develop this low intensity, high energy beam from the Moon and then by satellite, could that be used as a danger to other countries? I mean, if you had a hostile country that did that, could they use that in a negative way, Dr. Glaser?

Mr. GLASER. I'm delighted to tell you that this has been looked at already by NASA and the Department of Energy. Eventually, this will have to be under some international legal and regulatory framework just as we have communication satellites under international legal regulatory framework. I believe that there's enough evidence that would show that if anybody would try and do something different, first of all, I believe that eventually, just like in Intel South, there will be some international ownership. I believe Intel South is owned by 128 countries.

Eventually, I could visualize it some time in the next century, we would actually have an international energy supply system from the Moon or from orbit or whatever the best approach would be. I think that this is, perhaps, the best way that we can make sure that nobody can misuse the power.

Mr. HASTERT. Well, I know our focus has kind of switched here to solar electricity, something that I've worked on in my career in the legislature and also here. It's something that we need to find. Society demands that we find clean energy. This society and a future society will demand more and more energy. How we get it without burning fossil fuel or—how to find new places to store spent nuclear high level energy. It's just an enigma around this place, how we get those things done. So it's interesting. I'm going to ask Dr. Berendzen, you're an educator—American University—as well as an astronomer. What trigger do you need, because you work with young people all the time, to get them excited, involved and committed to this type of endeavor for their future?

Mr. BERENDZEN. I think they're ready to go. I think what they need is to know that the Nation is ready. It strikes me that during the Apollo era, we had a focus. We had a purpose. We had a dream. We had a goal. We had a date certain. And then we did it. And then we lost it. At the end of Apollo, how curious the history books of the future will be written.

Can you imagine someone writing a history book 500 years from now. Back in that time, in the United States, they decided to leave the Earth. They went to the Moon. They took those first steps. And then they came back again, sort of like a child putting their foot in the cold water of the ocean and retreating; they didn't return. Our space program began to lose it's focus. The *Challenger* disaster hit hard. The flaw in the Hubble certainly hurt. The end of the cold war removed the competitiveness that we once had.

What I urgently plead, if I might summarize much of what I've heard in the last few hours, is that this committee continue on with your series of hearings, that, perhaps, you collaborate with some of the other committees and subcommittees that are interested in these matters, as well. That there is a need, I believe, for a general education, dialog, discussion involving Members of Congress, NASA and the American public generally. What is needed ultimately are long-term plans: realistic, visionary, bold plans.

I happen to have had the honor of serving on the Exploration Advisory Task Force to NASA headquarters. We were in place at the time that President Bush came to this very building to announce that we would return to the Moon, this time to stay, and then go on to Mars. We gave a date certain: by the 50th anniversary of Apollo. It didn't come with funding, however. But it gave me an opportunity, at the request of NASA, to come in and go through all of their files on everything that had been done about this.

You know how many studies have been done, how many hearings have been held? The report of Dr. Webb. The Sally Ride report. The Synthesis report. The files are filled with it. How many of them have been implemented? Virtually none at all. The fact is that while we take enormous pride in the things around us, much of this is history.

My concern is the history of the future. In my testimony I said it's not a question of if, but it's a question of when and who. And the fact is, our competitors are moving now. And I hope the United

States can restate itself with young people as the leader in the world.

Mr. HASTERT. Thank you, Doctor. I think that brings us to a fine conclusion. I appreciate your contribution today. It certainly has sparked our imagination a different way, different from the first panel. Certainly, that is the future. We have to start to focus and you've made a great contribution.

This concludes our hearing for today. The meeting of the subcommittee is adjourned.

[Whereupon, at 11:40 a.m., the subcommittee was adjourned.]

DEFINING NASA'S MISSION AND AMERICA'S VISION FOR THE FUTURE OF SPACE EXPLORATION—PART II

MONDAY, MAY 19, 1997

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON NATIONAL SECURITY, INTERNATIONAL AFFAIRS, AND CRIMINAL JUSTICE,
COMMITTEE ON GOVERNMENT REFORM AND OVERSIGHT,
Washington, DC.

The subcommittee met, pursuant to notice, at 9:15 a.m., in room 2154, Rayburn House Office Building, Hon. Dave Weldon presiding.

Present: Representatives Weldon, Morella, Davis of Virginia, and Turner.

Staff present: Robert Charles, staff director; Ianthe Saylor, clerk; Mark Stephenson, minority professional staff member; and Ellen Rayner, minority chief clerk.

Mr. WELDON. Good morning. Due to unforeseen weather and some other circumstances, specifically, the death of a friend; Chairman Hastert and Vice Chairman Souder are unable to be here. Accordingly, I will act as the Chair this morning until one of the Members arrives.

This is the second in a series that this subcommittee will conduct on the topic of NASA oversight and the future of space exploration. The first of these hearings was held last week at the Air and Space Museum and was highly educational.

Our purpose today, is to focus on defining NASA's and the Nation's long-term mission in space. Beyond this day, we begin to examine narrower and perhaps more short-term issues. But today we are discussing vision, direction, and long-term oversight.

Since we have two remarkable and historic panels today, I will keep this opening brief. In my view, there are great untapped opportunities in the development of space, including space-based resources and well planned, well managed space exploration missions.

Historically, we know that this Nation has derived enormous benefits, both direct and indirect, commercial and national security related, from seeking and achieving great goals in space. I think we also know that there has been noticeable slippage since the glory days of Mercury, Gemini, and the Apollo programs.

Today, we bring before us a range of extraordinary witnesses to ask the pivotal questions: Where should America, both NASA and we as a Nation, be headed? What are the top competing ideas, and how do we get the Federal Government back on track? How do we regain the tight focus that, as a Nation, we once had in the realm we call space, and how do we pass on to our children the inspiration and legacy, mission orientation, and sorts of advances in engineering and science that Mercury, Gemini, and Apollo made possible for us 30 years ago? In short, what should this Nation's vision be, and how do we achieve it?

Let me just make a final note. In Washington, much of what we do and what I do as a Congressman relates to our kids, and the future. How do we make the future that we pass on to them as bright and promising, as daring and rewarding, as the one that was passed on to us.

So with that, let me say that I am eager to hear the words of our two distinguished panels. I would like to add that the ranking minority member, Tom Barrett, though very supportive of this hearing, was unable to be here this morning.

Now at this point, if I could, I would like the first panel to rise to be sworn in.

Please stand and raise your right hands.

[Witnesses sworn.]

Mr. Weldon. Let the record show that the witnesses responded in the affirmative.

Now I would like to formally welcome our first panel. Scott Carpenter is the former *Mercury 7* astronaut. It is also worth noting that he flew the second American manned orbital mission. He piloted his *Aurora 7* spacecraft through 3 revolutions of the Earth, reaching a maximum altitude of 164 miles. He has also written two novels.

Gene Cernan flew on three separate space missions. He was the second American to walk in space as the pilot of the *Gemini 9,* one of a crew of three to venture to the Moon on *Apollo 10,* and, as commander of *Apollo 17,* he holds the distinction of being the last man to leave his footprints on the surface of the Moon. He is currently president and CEO of the Cernan Corp. and the Cernan Group, which are space-related technology and marketing consulting firms.

Dr. Buzz Aldrin is a man who needs no introduction. All of you know that he piloted the lunar module on *Apollo 11,* the first manned mission to the Moon, and he was one of the first men to walk on the Moon. You may also know that Buzz was already a war hero before he ever became an astronaut, having flown 66 combat missions in Korea. Buzz is also a scholar, who earned his Ph.D. from the Massachusetts Institute of Technology for his scientific work on space flight.

We welcome all of you and look forward to your testimony. Mr. Carpenter, if you could proceed now.

STATEMENTS OF SCOTT CARPENTER, *MERCURY 7* ASTRONAUT; CAPTAIN EUGENE CERNAN, *GEMINI 9, APOLLO 10,* AND *APOLLO 17* ASTRONAUT; AND BUZZ ALDRIN, *APOLLO 11* ASTRONAUT

Mr. CARPENTER. Thank you very much, Mr. Chairman, and thank you for this opportunity to speak my mind about our space program.

I believe that if we as a Nation are to properly direct our space flight efforts in the next five decades, we should first examine our decisions and our triumphs and our failures in space flight during the last five decades. In the mid to late forties, we had the bomb, we had won the war, and we were king of the mountain, our Nation was secure, and we were complacent. We did then completely overlook the sleeping giant that was the Soviet Union. National security was looking at a very real threat, and we played catchup for the next 15 to 20 years in science and engineering, aeronautics, and space flight. International prestige and national security were at a low ebb.

But the cold war had a surrogate, and that was the constructive Soviet and American competition in space flight. It replaced in our struggle for world dominance the destructive competition that would have been war, and I honestly believe that that fight for preeminence in space kept us out of war. Also, I honestly believe that all of the close calls that world peace had in those years came from our own complacency.

Could that happen again? We have now won the race to the Moon. The Soviet Union has crumbled, and we, for the most part, are king of the mountain again. But beware complacency. China lurks.

During the early days of the space program, we had two precious gifts. One was the vision of Jack Kennedy, which inspired us. The other was the genius of von Braun, which enabled us. We don't have them with us today to show us the way, but maybe if we can all band together to express our faith in and share our vision of the future, we can avoid repetition of past mistakes.

I could give you, but to no avail, and you have seen probably to no avail, endless lists of specific advances in technology and spinoffs in science that are expected to accrue to us from continued space exploration and habitation. But those specifics are all trees. We should be looking at the forest.

Likewise, we should be looking as best we can at what we might expect to come to us from a vigorous space program 50 years from now, not 5 years from now. Helpful in this regard might be a look at how our present lives have been changed and enriched by the birth of space flight 50 years ago.

If we do that, we see the forest and not the trees, and that forest justifies every penny we spend in space. The forest is simply new knowledge in every discipline you can name. That is my abiding faith. My own private evaluation of where we once were and where we are now proves to me the truth underlying my faith. I believe any thinking man who looks carefully at the progress of science over the ages must share my faith.

Some look at the past and still ask the question, why? I say to them, if you must ask the question, you will never understand the answer. Space flight is not without risk. All of us who do it know it. But the benefits derived far outweigh the risks involved, and all of us who do it know that too.

Nothing of value is gained without some risk. If we are to keep our Nation prosperous and secure and keep the spirit of our people alive, then we must take some risks, we must tackle the unknowns with boldness, and rise from the ashes of our failures with new resolve and define and seek our future with vision.

As stewards of the Nation's future, I ask you, and in light of the last 20 years I may even implore you, for the sake of my grandchildren and theirs and yours, and indeed for the generation represented by a young man who will speak to you soon, Josh Ouellette, who wishes to be a space man and who, I remind you, will live for 50 years of his active scientific contributions with what we decide to do today, I ask you, for all of those, to keep us actively involved in space station construction and in vigorous exploration of space.

And as a justification and as a target for now for all we plan to do in space, let's use Mars and all the new truths that lie hidden there.

I thank you again for this opportunity and your attention.

Mr. Weldon. Thank you, Mr. Carpenter.

Mr. Weldon. Now Mr. Cernan. Let the record show that Mr. Cernan's dedication to the space program is so strong that he did not allow an adverse encounter with a bull yesterday—or was it the day before yesterday? I am not sure—to interfere with his decision to come out here.

So we appreciate you being here.

Captain CERNAN. Thank you, Mr. Chairman.

I think we can call my close encounter with a 2,000-pound longhorn bull not necessarily an act of God, probably somewhat induced by me. I apologize for appearing with this barroom-brawl-looking complexion I have. I find a lot of inquisitive people here who are too curious to ask me what happened. But suffice to say, it was a close encounter with somewhat of a natural disaster.

I, too, am very honored to be here. I appreciate the opportunity to express my views on something that has become very near and dear to me, and that is the future of this country, the slant toward my experience of course in space, and what I believe space has contributed not just to the past but potentially to the future of the country that, as Scott says, our children and grandchildren are going to grow up into.

At exactly 12:40 a.m., Eastern Standard Time on December 14th, 1972, I left mankind's final footsteps of Apollo on the surface of the Moon. As my partner, Jack Schmitt, and I departed, we echoed the words that, "Some day we shall return," that *Apollo 17* was not the end, but rather it was the beginning, the beginning of a whole new era in the history of mankind. And a few days later, when I returned to Earth from my second journey to the Moon, I boldly and confidently predicted that we would be on our way to Mars by the turn of the century.

We had 28 years to prepare for the next giant leap. What I did not anticipate, however, was that the beginning of which we spoke would be far more than a generation in coming and that the future might well be challenged by other than Americans.

But if Apollo was the beginning, what became of that future? Where are the dreams and the visions today? And where is the resolve and the commitment that challenged us to learn to live and to work in space and ultimately to venture a quarter of a million miles into the endlessness of time and call, if only for a short while, places like Tranquility Base and the Valley of Taurus-Littrow, our home.

Is it still possible for an American President to take as bold a step as John F. Kennedy did in 1961 when he answered the world's call to challenge Sputnik and set this country's sights on the Moon? That was the day America dared to become a space-faring Nation. Or, has our no-risk, "what is in it for me" culture of the past quarter of a century taken control of our destiny?

I happen to believe it is possible, but only when our leaders in both government and industry accept the reality that space is not now nor ever has been a luxury but a necessary ingredient to our position of world leadership and to the economic future well-being of each and every American.

My hopes soared when President Bush announced back on July 20, 1989, the 20th anniversary of *Apollo 11,* that we would return to the Moon, and this time to stay. Could it be that we once again had a President who not only reflected upon the past but understood the significance and importance of a national commitment to the future? President Bush then expanded his spacial exploration initiative by setting the year 2019 for a manned mission to Mars.

I believe it doesn't really matter what the date is, whether it be 2012, 2019, 2020, or whatever. What I do believe is of far greater significance is that this Nation have an ambitious yet attainable goal that reaches out a generation, a generation into the future, a goal the entire country, both young and old, government and industry, can get our arms around, a continuing national goal that transcends political boundaries, one that is not challenged, one that is not changed, one that is not canceled only to be reborn every 4 years. The infrastructure to support such a goal could well be the model for our future industrial and technological evolution.

But some in Congress at that time had their sights set on stopping our renewed space effort before it even had a chance to be debated. The congressional subcommittee that appropriated money for NASA somehow saw reasons to delete all funds for President Bush's space exploration initiative. They said that space exploration could wait until next year, as, unfortunately, it has waited for each of the last 25 years.

But can America wait forever to renew our exploration of space? Is Congress right when they postpone the challenge to better understand our own planet and this universe in which we live? Let's take a look at what is now at stake.

Three decades ago, the United States and the Soviet Union were the only countries in the world who even dared to dream of going to the Moon and together we owned space. Not so any more. In recent years, Japan has had plans to launch a probe to the Moon, the first Earthly object directed there since the early 1970's, and in 1989 the Japanese established a scholarly journal to publish ideas on how to go to the Moon, live on the Moon, and, most importantly, use the Moon for economic benefit.

In the near future, Japan plans a series of probes aimed at exploring lunar resources for their own industrial and economic potential. Clearly, clearly, many nations, particularly those known for long-term investment and economic success, have targeted space as a growth industry of the 21st century. In addition to Japan, we have only to look at the European industrial community today and, as Scott said earlier, to China as well.

But why space? What is in it for us? If we take a moment to reflect upon history, upon the accomplishments of more than a quarter of a century, upon the impact of space on medicine, communications, computer technology, as well as those things that are now an integral part of our everyday lives, it is then that we must acknowledge the importance of the foundation of technology from which this Nation has flourished.

This foundation of technology has been nurtured and continued to grow for over 100 years, allowing the United States to reach for and achieve greatness as a world leader of civilized mankind today. This technological base has not only allowed us to gain a technical and scientific understanding of the universe in which we live but to achieve international stature, political leadership, and economic affluence and well-being second to none other anywhere in the world.

Today, the brightest spot in the U.S. balance of trade continues to be the aerospace industry. Tens of billions of dollars per year pour into this country from our overseas commercial and military aircraft sales. This unique situation did not come about by chance but, rather, as a result of over 80 years of U.S. investment in research and development.

This technological legacy so important to the past is equally important to the future, and I believe space can be its cornerstone. Today there is even more at risk than there was in 1961. There are challenges to our technological leadership on all fronts from all corners of the globe by countries once perceived as our own private international marketplace. Never were these countries perceived as a competitor, much less as our technological equal.

Now, in this decade of peace, unless we find a vehicle for carrying forward the research and development upon which our economic influence and world leadership depend, the foundation of which I speak might well crack and crumble, and I believe that vehicle is space.

But true space exploration can have an even greater impact on our lives than that of technological progress alone. Education is the most far-reaching and crucial problem this Nation faces today. Americans everywhere decry our second-rate educational standing in the world. The problems are particularly acute in the critical science and engineering disciplines. It is bad enough if our youngsters don't know where Europe is, but if they are unable to read or write, our situation quickly becomes intolerable.

It is a well known fact that the U.S. Space Program provided an enormous impetus and incentive for technical education during the Apollo days of the 1960's. Our production of scientists and engineers tracked the increases and, unfortunately, the decreases in our space exploration effort. During the 1960's, we not only produced outstanding technical people, but the lure of space attracted the best and brightest young minds from overseas as well.

Now, as we approach the challenge of the 21st century, it is a sad commentary that we produce only half as many scientists and engineers and over half of those are foreigners who return home to enrich their own countries' economic competitiveness and not ours.

But good education requires more than better facilities, committed teachers, and modern equipment. It takes inspiration for our students to excel, and there is no greater inspiration for our children than the challenge and opportunity to explore the unknown, and no greater unknown than the universe in which we live.

It has now been 25 years, a quarter of a century, since I left those final footsteps on the Moon. Today we have a college-age generation of young men and young women who were born into this world after those last steps were taken, a generation of youth in a world today who never knew when man didn't walk in space or called the Moon his home. That, gentleman, is in itself an incredible thought.

Perhaps even more startling is the fact that it may well be a generation or more before we undertake a journey of such magnitude again.

I would like to reflect for just another moment or two because Apollo has been called by many the greatest technological endeavor in the history of mankind, and perhaps it may well have been. I believe, however, Apollo was much more. I believe it was a human endeavor unmatched in modern history. It was an endeavor not of a few chosen individuals who had the opportunity to step on the surface of the Moon but, rather, a team of thousands of Americans who were dedicated and committed to a goal deemed by many unattainable.

Apollo required this Nation to reach further than man has ever reached before. This team of Americans left an indelible mark on each of us here today and on all of those to follow in our footsteps tomorrow. Apollo encompassed the vision of a President and the effort, dedication, courage, self-sacrifice, and steadfast determination of an entire Nation of people, just as JFK said it would, a Nation of people who overcame the tragedy of the *Apollo 1* fire, an event that would have deterred a lesser people, and who would just not quit during *Apollo 13,* when we came closer than most of us even knew then of condemning three human beings to the endlessness of space.

Apollo 13 was an example of teamwork and commitment unequaled and now recognized as perhaps the finest moment of Apollo. We earned the right to celebrate our triumphs, and God knows we have paid dearly for our mistakes. Yet this team of Americans, together with common commitment and purpose, transformed what was once but a monumental dream into the reality of a generation. Together, they accepted the challenge and made each of those steps taken on the Moon possible.

It was a human endeavor of immense proportions by those who dared to dream, by those who dared to reach beyond our grasp, and by those who were not deterred by failure. Together, they just did not know it could not be done, and therein, I believe, lies the essence, lies the legacy of Apollo.

But as we reflect upon the past, it is essential that we look toward the future as well. Will the time come when we are once again a space-faring Nation and truly explore the wonders of the universe in which we live? Will we ever again voyage to the stars, or will we confine ourselves to circling a few miles above our home planet? Will we ever in our lifetime again be able to look back from a quarter of a million miles away at the majestic beauty of our own star in heavens, across the entirety of oceans and continents, at the Earth revolving on a unseen axis at that earthrise, first seen on *Apollo 8,* which changed the way we look at ourselves forever and at those sunrises back here on Earth and sunsets that we found just happening?

Will our children and our grandchildren, born after those final steps of Apollo, ever have the opportunity to see our stars as we once did and perhaps conclude as well that there must be a creator of the universe in which we live?

Although this Nation appears destined to remain home for the foreseeable future, I believe without reservation that some day we will once again satisfy our insatiable desire to explore and to discover the unknown, a dream of our forefathers thousands and thousands of years ago.

The opportunity to know and understand is now within the reach of our children, and I submit to you that they will not be denied. I find that youngsters, like this young man Joshua, whom you will hear from in a moment, no longer look at going to the Moon or on to Mars as an impossible dream as we once did but, rather, something that they can do simply by deciding to do it once given the opportunity.

The implications on education and the use of space as a motivational tool for learning are indeed far-reaching. I know. I have a daughter who teaches fourth grade right here in Fairfax County.

That next giant leap in space not need be solo. The first voyage to Mars might well be an international effort involving many countries. Still, there is great risk to our economic security if the United States does not have a stable and ambitious space program of our own. If we back off and say we have done it all, we have gone to the Moon, we have developed a space shuttle, and let others buildupon our technological competence, we will find ourselves in an unacceptable position both politically and economically. We cannot afford not to be in a position to influence the course of the next giant leap in space and ultimately to determine our own destiny.

As President Bush reminded us, "History tells us what happens to nations that forget how to dream."

Gentleman, there is too much at stake to turn back now. We must not allow our once proud resolve to turn into indifference, for what we as a Nation leave undone today will certainly be done by others tomorrow.

We have challenged the future. Those that follow have only to understand the significance of that challenge so as to ultimately determine their own destiny. Williams Jennings Bryant perhaps put it together and put it all in perspective at the turn of the last century when he said, "Destiny is not a matter of chance; rather, it is a matter of choice."

Thank you.

Mr. Weldon. Thank you for those eloquent words. I can obviously see a shot in the head from a longhorn bull didn't do you too much harm.

We are very pleased to be joined for this hearing by the distinguished Members from Texas and Virginia. If I could, I would like to recognize Mr. Davis from Virginia and ask him if he has any opening comments.

Mr. DAVIS. I am honored to be here before such a distinguished panel.

Captain Cernan, I have three kids in the Fairfax County public schools. That is my congressional district. It is the home of the Buzz Aldrin Elementary School. I was happy to be there with Dr. Aldrin when we opened it. I was out there with you and was there a couple weeks ago, and they read a note from Dr. Aldrin at that time and for Scott Carpenter.

Captain CERNAN. I might add, my daughter was selected the Outstanding Teacher in northern Virginia, and, without saying more, she truly does utilize space as a launching platform from which to teach everything, from poetry and English to math and leadership and science. It is a phenomenal experience to watch it happen.

Mr. DAVIS. Thomas Jefferson High School for Science and Technology is one of the premier science schools in the country. I think it has had more merit scholars for the last 3 years than any other high school in the country. It is by selection basis.

Which school is she at?

Captain CERNAN. I think it is Greenbriar West.

Mr. DAVIS. Greenbriar West is here on the Hill today. We have got some people coming from there for the Lunchbox Derby. I was going to try to get over to that as well.

Captain CERNAN. She is out with her students now, camping out for a week to teach them a few other things. She still motivates them through the use, as I say, of the desire to learn of space and the unknown. It is just a phenomenal experience to watch it.

Mr. DAVIS. You ought to go to Buzz Aldrin Elementary School. It is completely science and tech, and they are doing new things every time I go there.

As I say, Mr. Carpenter, I was a kid when you started. It is a great honor to be here today to hear you and get a chance to ask you questions later. Thank you very much.

Mr. Weldon. Mr. Turner, do you have an opening statement?

Mr. TURNER. I, too, am honored to be here on this panel before you three distinguished gentlemen, and I want you to know that, being from Texas, we are still very enthusiastic about the space program in Texas. I really think if we can do a little better job about defining our goals and establishing our goals in the minds of the American people, that we will return to those days of excitement and enthusiasm about the space program.

I think we are at a point where it is just much more difficult than ever before to clearly define that mission in the minds of the American people. But I think the spark of enthusiasm is still there waiting to be lit. I appreciate the three of you being here and the continuing work you do on the space program which, in my judgment, is so critical to the history of our country and of the world.

Thank you.

Mr. Weldon. Now we will proceed with Dr. Aldrin's testimony.

Mr. ALDRIN. Thank you, Mr. Chairman, for having me back to continue where I left off last week.

Today I would like to introduce a statement and then expand on some of the concepts I feel are significant to the future of our space program.

This summer, the planet Mars receives the first visitors from Earth in over two decades, and the space program will once again capture the world's attention and headlines for a brief few days.

But let me suggest the time has come to expand our vision and begin developing a strategy to best capitalize on the 40-year investment we have made in our space endeavors. The time has come to focus our efforts and to build a program that brings space benefits down to Earth that address and solve the problems of our home planet and at the same time expand freedom and commercial opportunity to the far reaches of our solar system.

I believe that early in the 21st century, men and women will call Mars a second home for humanity. But my vision evolved from a can-do spirit and resolve, a projection of American prowess, as well as foresight to establish a visionary plan that incorporates and maximizes reusability in our space program.

By resuming our investigations of Mars, we are adding new brush strokes to picture what will ultimately become our future in the cosmos. The picture I now see is of an undeveloped frontier that must be opened to human enterprise and settlement. To do so means pursuing an evolutionary, step-by-step, building block agenda that leads to a sustained space program that guarantees we tap the wealth of our solar neighborhood and, in so doing, transforms our space-faring civilization into a multiplanetary civilization.

It is becoming clear to me as we approach the new millenium how to do this best. However, it is also clear that the steps being taken by our Government's space planners do not have this longer-range vision in mind. For instance, the Department of Defense is pursuing a strategy using all-expendable throwaway rocketry. Meanwhile, NASA has set its future on a high-technology solution embodied in a single-stage-to-orbit vehicle. While each has merit, neither satisfies the need of the private sector for near-term lower launch costs to access and exploit the frontier.

Within a few decades, space can be an open frontier for all people. I see a near-term future where economical two-stage space launchers place passengers and cargo into Earth orbit with the efficiency and routine-like nature of today's airline traffic. A booming tourism industry will be cultivated as space hotels become a point of arrival and departure above our planet. This burgeoning business enterprise will bring about heavy-lift rockets, enabling grander steps of exploration back to the Moon, to the distant dunes of Mars and beyond.

I envision long-haul transportation systems, deep-space cruisers that not only continuously cycle tourists between the Earth and Moon but constantly transfer explorers and settlers between Mars and the Earth. A fully reusable lunar and interplanetary system is the ultimate way of transporting people and cargo across the vast vacuum void of space.

My own personal involvement as an *Apollo 11* astronaut on the first lunar landing mission taught me an important lesson. Everything that went with us on Apollo was thrown away, such as all the stages of our giant *Saturn 5* booster, save for the return capsule that brought us safely back to Earth.

Now, there is nothing wrong with Apollo. Its characteristics were born of the time. It was a cold war, one-upsmanship approach to out-distance the former Soviet Union. The Moon was the finish line. Apollo was founded on the straightforward space-race strategy, get there in a hurry and don't waste time developing reusability.

Today, I can't conceive of another global race, or cooperative effort, for that matter, that would prompt an effort to get to Mars, accomplish the goal, and then abandon the program. Yet the mind set of toss-away space hardware still dominates our thinking. We have gotten used to a throwaway space program perpetuated by a low volume of traffic from Earth into space.

Long ago we tamed the sound barrier. Now we must penetrate the reusability and recycling barriers to shape our 21st century space endeavors. But how can we rekindle the spirit of Apollo and match it with a sustainable evolutionary space program for the 21st century? I see an action plan for the future—you can call it 20–20 vision—based on years of training and experience this country so graciously invested in me.

As our next step, lowering the cost of space access with a reusable two-stage-to-orbit launcher is critical. Incorporating a fly back reusable first stage, this type of launcher would hurl another rocket-powered vehicle that can reach space with greater economy than a purely self-propelled.

By lowering the expense of attaining Earth orbit, many new industries are waiting to develop, one of which will be space tourism. Soon, tens of thousands of citizens will have the opportunity to travel into space, gaining a sense of participation in opening the frontier of space to enterprise, exploration, and eventual settlement.

From this step, an add-on to the reusable space program philosophy is building a bridge between worlds. Through a system of reusable spacecraft that I call cyclers, traffic routes, first between Earth and the Moon, then Mars and Earth, should be put in motion. Very much like ocean liners, the cycler system would perpetually glide along predictable pathways, moving people, equipment, and other materials to and from the Earth over inner solar system mileage.

A sequential buildup to a full cycling network could be in place within two decades of a go-ahead geared to the maturation of lunar and Mars activities. The Earth, the Moon, and Mars will form a celestial triad of worlds, busy hubs for the ebb and flow of passengers, cargo, and commerce traversing the inner solar system.

My schedule for accomplishing these objectives is practical, achievable, and affordable, drawing from decades of space expertise already honed by our early exploits, including the space shuttle and space station projects. I call for a strong and vibrant space tourism business and a return to the Moon by 2010, and then reaching Mars before 2020.

Frankly, I think we can beat that schedule. The common link between steps in this timetable is a progressive set of reusable boosters, reusable access to space, and then reusable interplanetary cyclers. This vision spans two decades of enterprise, exploration, and settlement. It should be wisely enunciated by a new U.S. President in the year 2001.

By the year 2030, I see people looking back and cherishing the moment that a leader of our country committed us to a gradual but progressive plan of permanent settlement of space, not just occasional visits that leave little more than flags and footprints.

The surface of Mars is equivalent to the land area of Earth. Once a human presence on this planet is established, a second home for humankind is possible. A growing settlement on Mars is, in essence, an assurance policy not only for the survival of the human race, not only is the survival of the human race then assured, but the ability of it to reach from Mars into the research-rich bounty of the Martian satellites and nearby astroids is also possible.

These invaluable resources can be tapped to sustain increasing numbers of Martian settlers as well as foster expanded interplanetary commerce and large-scale industrial activities to benefit the home planet, Earth.

Of course, some will insist on building outer-solar-system cyclers as humanity continues outbound into the universe at large.

My 2020 vision is a call for a sustained space program with long-range acuity. We can now chart a course that returns us to the Moon, then allows humanity to strike out for the new world of our future, the planet Mars.

But our near-term space efforts, both manned and robotic missions, must be tailored to support the longer-range purpose of opening the frontier. Step by step, program by program, we can construct a future of limitless potential. I must ask you gentleman, if not for these bold endeavors, then what is our space program for?

Please allow me to address four significant points that Congress, as a governing oversight body, can do to help guarantee that the vision I have described here today can come to fruition for future generations.

First, the highest priority of NASA and congressional oversight into NASA's activities must be to develop lower-cost-to-orbit systems. Congress should continue its leadership role in this direction by expanding the spectrum of development options beyond single-stage-to-orbit systems to include the gamut of reusable launch vehicle options, including two-stage-to-orbit systems.

Second, continue to identify and eliminate those stifling regulations that inhibit the private sector from competing in the commercial launch vehicle market to facilitate the development of low-cost transportation system options.

Third, focus near-term activity, both in NASA and the private sector, by adopting the long-range national goal to expand human presence throughout the solar system and to tap the unlimited power and resource potential of solar space.

Finally, charge NASA to study in depth these recommendations and the reusable cycling transportation system I have described for the economical exploration and development of the Moon and Mars.

Now, I would like to elaborate on some of these concepts by using some visual aids. This viewgraph shows the use of an existing very powerful, competent rocket, the Zenit rocket. It is a two-stage rocket that the Boeing Co. is going to use called Sea Launch on floating platforms to hopefully bring back the commercial launch business, back from the French, back to the United States. This Zenit rocket was part of the Energia heavy lift rocket launch, today the world's most impressive rocket.

What we propose to do is wrap an airplane around the first stage, run it through test programs, horizontal and vertical, mate it with itself for suborbital tourism, with upper stages. Two- and three-star boosters can be attached to this. This booster could lift the X–33 into orbit with several thousand pounds of payload, or, with the RLV, if it is ever financed and built, it could double its payload.

However, a better second stage reusable is probably preferred based on more ruggedness and perhaps external hydrogen tanks. This booster could be used as three replacement boosters for the solid rockets on the shuttle or as two replacements, one on each side, if the tanks are stretched on it appropriately. It forms the basis for a reusable, strap-on, heavy lift rocket system that puts up the hotels for tourists for the American people, and with that enthusiasm, we use that booster then to go back to the Moon, and second generations of that get us on to Mars.

I have a timetable for accomplishing these, and I will leave that up there for a while. But note that it involves the first tourist in Earth orbit that might use a commercial version of the return vehicle that is being prepared for the space station. That, with an upper stage and boosted into orbit by the star booster, would be a very competent first tourist opportunity. We are going to need the hotels in space.

Three or four-star boosters could give us the heavy lift. Then we could return to the Moon in 2008, phase 1 direct to the south pole of the Moon, variable gravity research, leading to expanded lunar operations and reusable lunar landers in phase 2 with sort of a rendezvous at L–1, the liberation point. It is more like the Apollo instead of direct to the surface.

This eventually grows to lunar cyclers for tourism that are the predecessors of the Earth-Mars cycling system that enables us an efficient system of getting to Mars, the moons of Mars first.

What I would like to show you over here is two examples of Earth, Moon cycler systems, where we take the figure 8 and then we go out on an ellipse several times before we go and encounter the Moon again. There is another version of this that goes out past the Moon, comes back, swings around the Moon, the front side, and then back out again. That is more than a 30-day mission. It is probably not too usable as a transportation system for explorers, but it is ideal for tourism.

Looking at Mars, the Sun, the Earth and Mars line up at a date here in 2016. The next time they line up is after the Earth gets ahead of Mars and goes around once. Mars is over here. When the Earth goes around twice, Mars is still ahead of it. The two line up again 26 months later.

The significance of this is that in order to travel from Earth to Mars, you should be about halfway between Earth and Mars when this opposition time occurs. And if you wanted to leave Mars here for this opposition, you leave at this point and reach Earth back over here.

Now, a schematic of a cycler system that keeps the energy of the interplanetary vehicle when it reaches Mars so that it doesn't have to slow down and stop and then use fuel to depart Mars again is in this diagram here. When you swing by Mars, we would go at a plane from Mars, swing by half a revolution later. One revolution later, we convert that velocity back to bring us back toward the Earth.

At the Earth, between the opportune times to go from Earth to Mars and Mars to Earth, we have to wait about 18 months. That allows us to go out of plane from the Earth's orbit around the Sun for 6 months, 6 months and another 6 months, before we convert by gravity assist in swinging back to Mars.

It is a fascinating system, and in more detail you can see it on this inertial plot where we show transfer down here from Earth to Mars. We would wait for one revolution at Mars and then return back to Earth over here. We would make an orbit and a half of the Sun and then go back to Earth.

It has been a really great challenge for me to take the knowledge that I have accrued in my educational system and my experience of being an astronaut and to project this into the future to learn as much as possible about how to make economical systems, challenging systems.

I think that tourism is within the next 10 to 15 years. It will enable the Moon to be returned to and open up Mars. The space frontier is ours for the use, for the grasping. The decision is ours, and let's go for it.

Thank you, Mr. Chairman.

[NOTE.—"Ad Astra," the magazine of the National Space Society, May/June 1997, can be found in subcommmittee files.]

[The prepared statement of Mr. Aldrin follows:]

A VISION OF OUR FUTURE IN SPACE

By Buzz Aldrin

Thank you for having me back to continue where I left off last week. Today I would like to introduce a brief statement and then expand upon some of the concepts I feel are significant to the future of our space program.

This summer, the planet Mars receives its first visitors from Earth in over two decades and the space program will once again capture the world's attention and headlines for a brief few days. But let me suggest that the time has come to expand our vision and begin developing a strategy to best capitalize on the 40 year investment we've made in our space endeavors. The time has come to focus our efforts and to build a program that brings space benefits down to earth, that address and solve the problems of our home planet, and at the same time, expand freedom and commercial opportunity to the far reaches of our solar system.

I believe that early in the 21st century, men and women will call Mars a second home for humanity. But my vision evolved from a can-do spirit and resolve, a projection of American prowess, as well as foresight to establish a visionary plan that incorporates and maximizes reusability in our space program.

By resuming our investigations of Mars, we are adding new brush strokes to the picture that will ultimately become our future in the Cosmos. The picture I now see is of an undeveloped frontier that must be opened to human enterprise and settlement. To do so means pursuing an evolutionary, step-by-step, building block agenda that leads to a sustained space program that guarantees we tap the wealth potential of our solar neighborhood and in so doing, transform our spacefaring civilization into a multi-planetary civilization. It is becoming clear to me, as we approach the new millennia, how to do this best.

However, it is also clear that the steps being taken by our government's space planners do not have this longer range vision in mind. For instance, the Dept. of Defense is pursuing a strategy using all expendable, throw-away rocketry. Meanwhile, NASA has set its future on a high-technology solution embodied in a single-stage-to-orbit vehicle. While each has merit, neither satisfy the need of the private sector for near-term lower launch costs to access and exploit the frontier.

Within a few decades, space can be an open frontier for all people. I see a near-term future where economical, two-stage space launchers place passengers and cargo into Earth orbit with the efficiency and routine-like nature of today's airline traffic. A booming tourism industry will be cultivated as space hotels become a point-of-arrival and departure above our planet. This burgeoning business enterprise will bring about heavy-lift rockets enabling grander steps of exploration, back to the Moon, to the distant dunes of Mars, and beyond.

I envision long-haul transportation systems, deep space cruisers that not only continuously cycle tourists between the Earth and Moon, but constantly transfer explorers and settlers between Mars and the Earth. A fully reusable lunar and interplanetary system is the ultimate way of transporting people and cargo across the vast vacuum void of space.

My own personal involvement as an Apollo 11 astronaut on the first lunar landing mission taught me an important lesson. Everything that went with us on Apollo was thrown away -- such as all the stages of our giant Saturn V booster -- save for the return capsule that brought us safely back to Earth. There was nothing wrong with Apollo. Its characteristics were born of the time. It was a Cold War, oneupsmanship approach to out distance the former Soviet Union. The Moon was the finish line. Apollo was founded on a straightforward, "space race" strategy: "Get there in a hurry and don't waste time developing reusability."

Today, I cannot conceive of another global race, or cooperative effort for that matter, that would prompt an effort to get to Mars, accomplish the goal, then abandon the program. Yet the mind-set of toss-away space hardware still dominates our thinking. We have gotten used to a throw-away space program, perpetuated by a low volume of traffic from Earth into space. Long ago, we tamed the sound barrier. Now we must penetrate the reusability and recycling barriers to shape our 21st century space endeavors.

But how can we rekindle the spirit of Apollo, and match it with a sustainable, evolutionary space program for the 21st century?

I see an action plan for the future - call it 2020 vision based on years of training and experience this country so graciously invested in me.

As our next step, lowering the cost of space access with a reusable two-stage-to-orbit launcher is critical. Incorporating a "flyback" reusable first stage, this type of launcher would hurl another rocket-powered vehicle that can reach space with greater economy than if purely self-propelled. By dropping the expense of attaining Earth orbit, many new industries are waiting to develop, one of which will be space tourism. Soon, tens of thousands of citizens will have the opportunity to travel into space, gaining a sense of "participation" in opening the frontier of space to enterprise, exploration and eventual settlement.

From this step, an add-on to the reusable space program philosophy is building a "bridge between worlds." Through a system of reusable spacecraft that I call "Cyclers", traffic routes -- first between Earth and the Moon, then Mars and Earth -- should be put in motion. Very much like ocean liners, the Cycler system would perpetually glide along predictable pathways, moving people, equipment, and other materials to and from the Earth over inner-Solar System mileage.

A sequential buildup of a Full Cycling Network could be in place within two decades of a go-ahead, geared to the maturation of lunar and Mars activities. The Earth, the Moon, and Mars will form a celestial triad of worlds - busy hubs for the ebb and flow of passengers, cargo and commerce traversing the inner-Solar System.

My schedule for accomplishing these objectives is practical, achievable and affordable, drawing from decades of space expertise already honed by our early exploits, including the Space Shuttle and Space Station projects.

I call for a strong and vibrant space tourism business and a return to the Moon by 2010, then reaching Mars by 2020. Frankly, I think we can beat this schedule. The common link between steps in this time table is a progressive set of reusable boosters, reusable access to space, then reusable interplanetary Cyclers.

This vision spans two decades of enterprise, exploration and settlement. It should be wisely enunciated by a new U.S. President in the year 2001. By the year 2030, I see the same people looking back and cherishing the moment that a leader of our country committed us to a gradual, but progressive plan of permanent settlement of space, not just occasional visits that leave little more than flags and footprints.

The surface area of Mars is equivalent to the land area of Earth. Once a human presence on this planet is established, a second home for humankind is possible. A growing settlement on Mars is, in essence, an "assurance" policy. Not only is the survival of the human race then assured, but the ability to reach from Mars into the resource-rich bounty of the Martian Satellites and the nearby asteroids is also possible. These invaluable resources can be tapped to sustain increasing numbers of Martian settlers, as well as foster expanded interplanetary commerce and large-scale industrial activities to benefit the home planet-- Earth. Of course, some will insist on building outer-Solar System Cyclers as humanity continues outbound into the Universe at large.

My 2020 vision is a call for a sustained space program with long-range acuity. We can now chart a course that returns us to the Moon, then allows humanity to strike out for the New World of our future - the planet Mars. But our near-term space efforts, both manned and robotic missions, must be tailored to support the longer-range purpose of opening the frontier. Step by step, program by program, we can construct a future of limitless potential. I must ask you gentlemen, if not for these bold endeavors, then what is our space program for?

Please allow me to address four significant points that Congress, as a governing oversight body, can do to help guarantee the vision I have described here today can come to fruition for future generations.

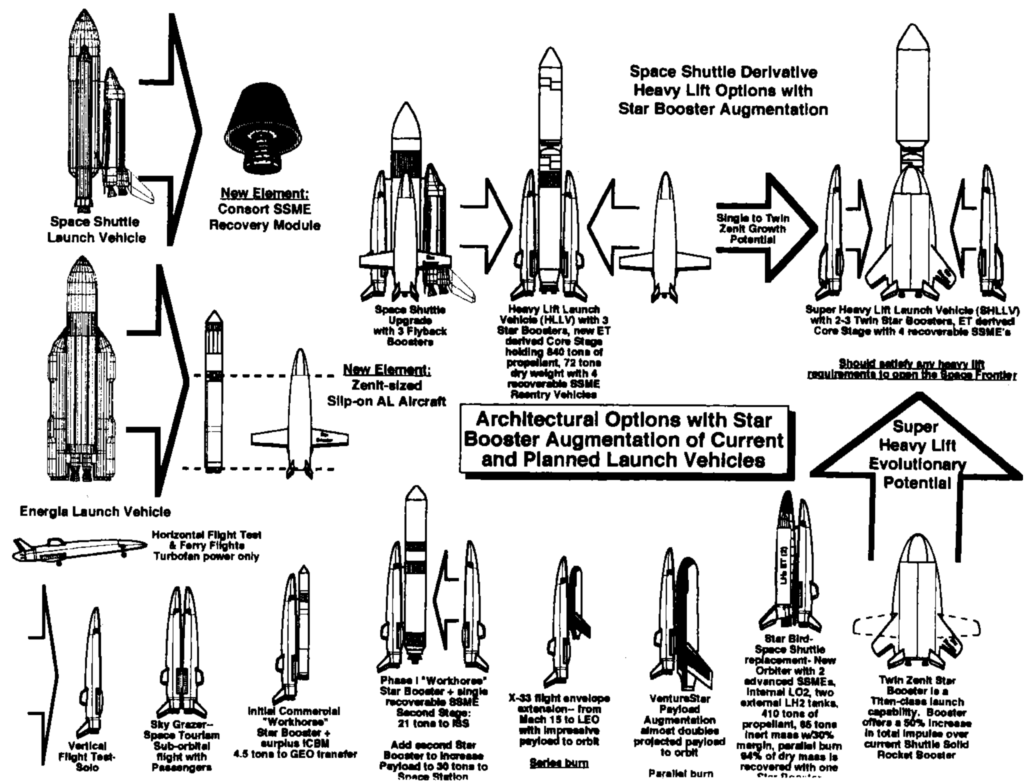
- First, the highest priority of NASA and Congressional oversight into NASA's activities must be to develop lower cost to orbit systems. Congress should continue its leadership role in this direction by expanding the spectrum of development options beyond single-stage-to-orbit systems, to include the gamut of Reusable Launch Vehicle options including two-stage-to-orbit systems.

- Second, continue to identify and eliminate those stifling regulations that inhibit the private sector from competing in the commercial launch vehicle market to facilitate the development of low cost space transportation system options.

- Third, focus near-term activity both in NASA and the private sector by adopting the long range national goal to expand human presence throughout the solar system and tap the unlimited power and resource potential of solar space.

- And finally, charge NASA to study in depth these recommendations and the reusable cycling transportation system I have described for economical exploration and development of the moon and Mars.

Now, if I may elaborate on some of the key concepts I feel are significant to the near-term health of our space program...


Space Shuttle Launch Vehicle
New Element: Consort SSME Recovery Module
Space Shuttle Derivative Heavy Lift Options with Star Booster Augmentation
Space Shuttle Upgrade with 3 Flyback Boosters
Heavy Lift Launch Vehicle (HLLV) with 3 Star Boosters, new ET derived Core Stage holding 840 tons of propellant, 72 tons dry weight with 4 recoverable SSME Reentry Vehicles
Single to Twin Zenit Growth Potential
Super Heavy Lift Launch Vehicle (SHLLV) with 2-3 Twin Star Boosters, ET derived Core Stage with 4 recoverable SSME's
Should satisfy any heavy lift requirements to open the Space Frontier
Energia Launch Vehicle
New Element: Zenit-sized Slip-on AL Aircraft
Architectural Options with Star Booster Augmentation of Current and Planned Launch Vehicles
Super Heavy Lift Evolutionary Potential
Horizontal Flight Test & Ferry Flights Turbofan power only
Vertical Flight Test-Solo
Sky Grazer-- Space Tourism Sub-orbital flight with Passengers
Initial Commercial "Workhorse" Star Booster + surplus ICBM 4.5 tons to GEO transfer
Phase I "Workhorse" Star Booster + single recoverable SSME Second Stage: 21 tons to ISS
Add second Star Booster to increase Payload to 30 tons to Space Station
X-33 flight envelope extension-- from Mach 15 to LEO with impressive payload to orbit
Series burn
VentureStar Payload Augmentation almost doubles projected payload to orbit
Parallel burn
Star Bird- Space Shuttle replacement- New Orbiter with 2 advanced SSMEs, internal LO2, two external LH2 tanks. 410 tons of propellant, 65 tons inert mass w/30% margin, parallel burn 94% of dry mass is recovered with one
Twin Zenit Star Booster is a Titan-class launch capability. Booster offers a 50% increase in total impulse over current Shuttle Solid Rocket Booster

EARTH - MARS CYCLER SYSTEM

CYCLER I

① Depart. Earth 2016 Jan

② Arrive Mars July
Depart Mars 2018 May

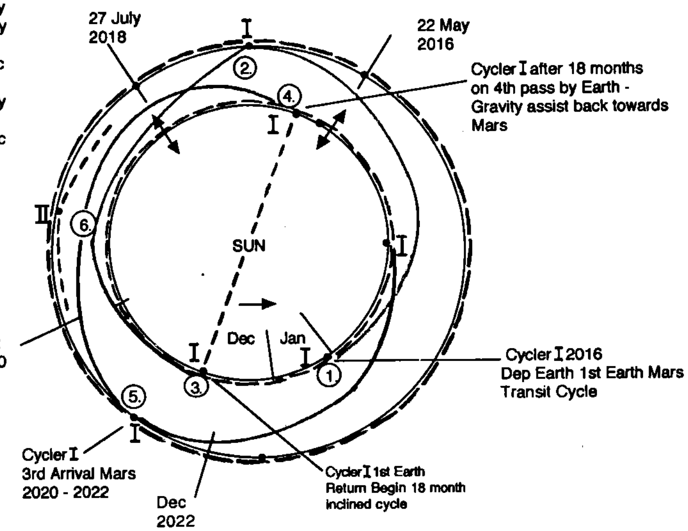
③ Arrive Earth Dec

④ Depart Earth 2020 May

⑤ Arrive Mars Dec

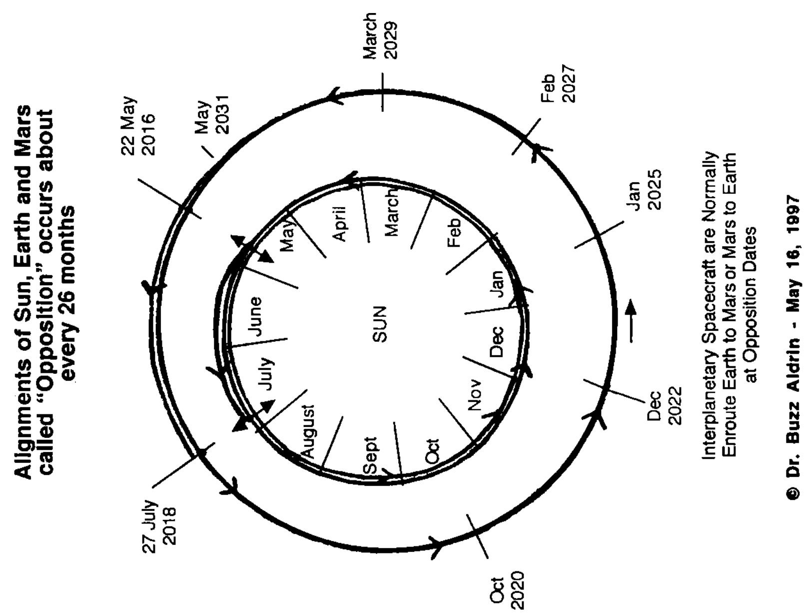
Cycler II

⑥ 2018 - 2020 Cycler II
2nd Arrival Mars
also with one Sun
orbit before return
to Earth



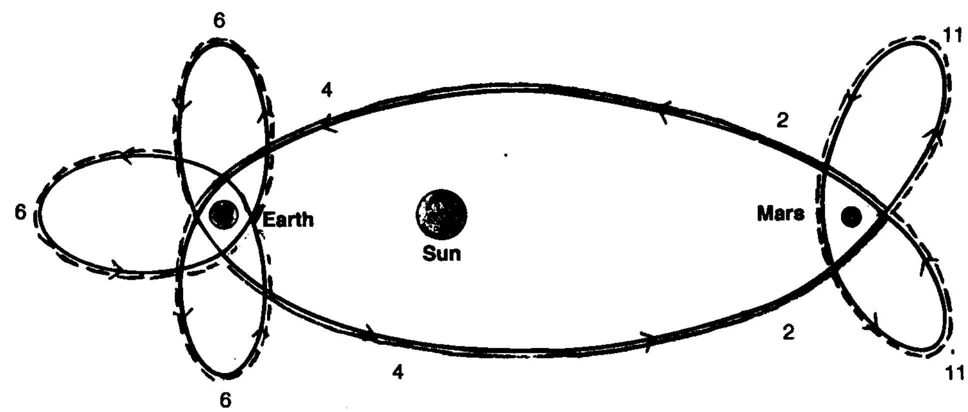
Going to Mars ———

Return to Earth ———



Alignments of Sun, Earth and Mars called "Opposition" occurs about every 26 months
SUN
Jan
Feb
March
April
May
June
July
August
Sept
Oct
Nov
Dec
22 May 2016
27 July 2018
Oct 2020
Dec 2022
Jan 2025
Feb 2027
March 2029
May 2031
Interplanetary Spacecraft are Normally Enroute Earth to Mars or Mars to Earth at Opposition Dates
© Dr. Buzz Aldrin - May 16, 1997

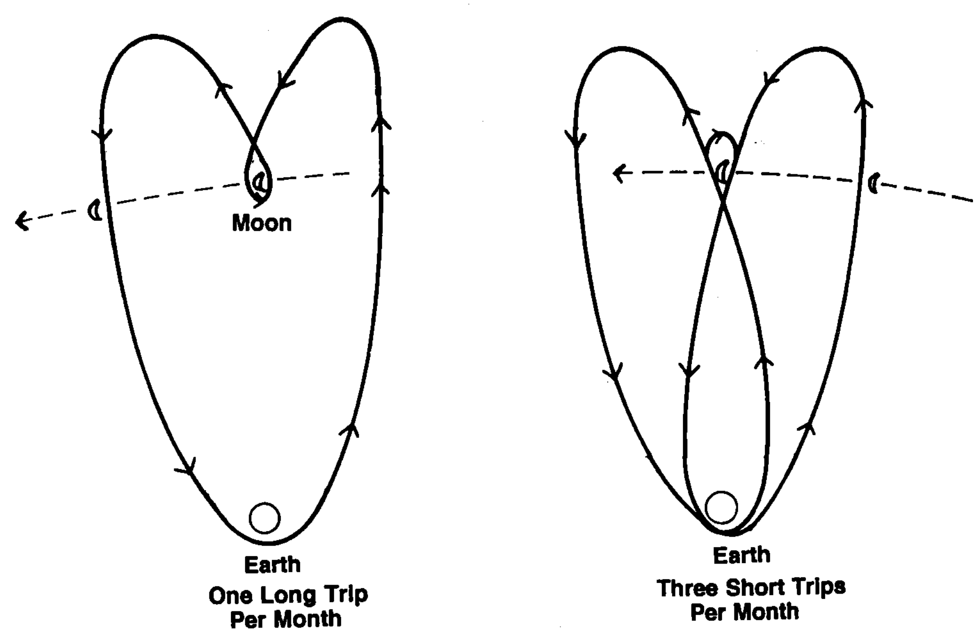
EARTH - MARS CYCLER SYSTEM - SCHEMATIC



Going to Mars ——

Returning to Earth ——

EARTH - MOON CYCLER SYSTEM



Key Milestones of Human Exploration and Development of Space

YEAR	MILESTONE	KEY ELEMENTS
2003	• First Stage RLV	Star Booster
04	• First Sub Orbital Tourism	Skygrazer
06	• First Tourists to Earth Orbit • Mars Sample Return	Star Booster/ACRV, X-38 Kistler, Others...
07	•Tourport Earth Orbiting Hotel	3-4 Star Booster Heavy Lifter Dry Workshop concept
08	• Return-to-Moon: Phase 1 Direct to Lunar South Pole • Establish Outpost • Lunar fuel production	Crew Transfer Vehicle lander (Derived from ACRV)
09	• Variable Gravity Research/ Engineering • Lunar Tourism Cycler Demonstration	"Hotel" becomes central hub of three components connected by cables that rotate producing artificial gravity
10	• Significant Lunar Base Power Capability • L1 Orbital Facility/Port • Increased Orbital Tourism	Surface Nuclear Power 09 Lunar Tour Cycler Demo facility moved to L1 Star Bird- New second stage Orbiter replacement
11	• Lunar Base: Phase II	Reusable Lunar Lander
13	• Lunar Tours- Regular Cycler Flybys	1 week to 1 month cislunar tours
14	• Phobos Surface Habitat Emplacement (Moon - Mars)	Super Star Booster Heavy Lifter
15	• Mars Cycler I- Earth Orbit/ Cislunar Test	Build upon VG research/ engineering & L1 Moonport
16	• Mars Cycler I Departs or Mars • Phobos Landing & Exploration	Dress rehearsal for Mars landing Hab & Fuel units detach from Cycler and land on Mars
17	• Mars Cycler II- Earth orbit and Cislunar Test	
18	• Mars First Surface Landing • Begin Exploration & Settlement Activities	Optional partial crew stayover to return every other opportunity

Mr. Weldon. Thank you, Dr. Aldrin, for that fascinating presentation.

Before we move on to the question and answer period, I would like to recognize a member of the committee, the distinguished lady from Maryland, Mrs. Morella, for an opening statement.

Mrs. MORELLA. Thank you, Mr. Chairman.

I am really not going to make an opening statement, but I did want you to know that I am on the Science Committee, which has space under its jurisdiction also, and I showed up this morning at the Air and Space Museum. Since you all weren't there, I did a tour of it. So it really prepared me for the hearing this morning. I appreciate you being here.

It is interesting, because this is cleanup time, isn't it, the spring cleaning happening on Mir and Atlantis, and this is something you all know full well, so I think it is pretty significant that at this time when we continue with the partnership with the Russians on the space station that we also have our shuttle that is changing things around and somebody who will be up there also for 4 months on Mir. A lot of exciting things are happening.

But I would agree with what I understand that you have said in terms of the fact that we need something that is long-range. We need to also excite our young people. I had the opportunity just last week to help to rededicate a school in Montgomery County, MD, called the S. Christa McAuliffe School. Her mother was there. And their whole theme is reach for the stars, touch the future.

I think that is also part of the theme that you have been generating in terms of motivating young people, in terms of space exploration, all of the scientific endeavors that go along with it, the leadership, taking risks, long-term policy, the spin-offs. As a woman, I can see plenty of medical spin-offs that help, for instance, with breast cancer and a number of the other diseases where it would be helpful.

Mr. Carpenter, you were my neighbor once upon a time in Bethesda, MD, so it is good to see you again and also to kind of celebrate your achievements.

Dr. Aldrin, I read your testimony from last week where you appeared, and I mentioned some of your themes at that time which were like education, faith, and commitment; pretty much that was it; and I thought your explanation of it was also very good.

So I look forward to the line of questioning. I thank the chairman for the opportunity to thank you for being here and what you represent. I hope the whole world can see what you have done and what you see as our vision and mission for the future.

Thank you.

Mr. Weldon. I would like to begin the question and answer period, recognizing the gentleman from Virginia, Mr. Davis.

Mr. DAVIS. Let me ask—I guess our next panel will get into this in some more detail—do we presently have the life support systems that would be required to send somebody to Mars? If not, do you think this is easily achievable? I will start, Mr. Carpenter, with you, if you know, or Captain Cernan. Do any of you have a feel for that?

Mr. ALDRIN. That is what the space station is for. The space station is to prove out the scientific needs that we have for continued use of space, and life science is one of the major ones, and long-duration space flight on the space station, longer than the shuttle itself can stay up. That is why the Russian experience is so valuable to us, that they have been able to stay up for 6 months at a time and several of them for over a year. The life support systems that they have developed are going to be very useful for us to learn from and then develop our own systems.

Mr. DAVIS. I guess you would say, in summary, we may not be there but we are on our way, we are getting good data and need to expand on that.

Captain CERNAN. Can I give you a historical analogy? When JFK challenged this country to send a man to the Moon back in 1961, he did so within 3 weeks after Alan Shepherd flew, the first American in space. Alan flew for 16 minutes and had not yet even achieved orbit, and JFK said we are going to go to the Moon.

We didn't have boosters, we didn't have environmental control systems, we had never gotten out of a spacecraft, we had not even been in orbit, we didn't have anything it took, but it was a challenge. It was the fact that he challenged people to do something, as I said earlier, that most people thought couldn't be done, that evolutionized that technology necessary to get us to the Moon; computer technology.

When I think about where we ended up in Apollo and where we started when JFK said we are going, none of that existed. So, I don't look at that as a problem; I think it is a commitment.

If we decide we are going to go to Mars, if we put together a long-term national commitment that looks at a generation in the future, the infrastructure resulting from that equipment that is going to evolve from it, there is going to be a whole industrial base.

As I said earlier, to me, although there may be other reasons because of the location of the Moon, Mars, and so forth, as to what year we could, that is less important than the fact that we commit ourselves to go at some point in the future. And if we want to detour on the way and go to Mars, if we want to detour and continue with the space station, if there are other things, if we find helium 3 on the Moon that is mineable, if we want to do other things, we have the option to do that if the infrastructure is in place. The technological requirements to get there, I think, are going to be fallouts of the commitments itself.

Mr. CARPENTER. I think it is also important to recognize that when Kennedy said we should go to the Moon, we didn't have the technology; we built it. But if someone were to tell us now we should go to Mars, we have the technology and we are in a much better position to do that than we were in 1961 to go to the Moon.

Mr. DAVIS. It looks like many of the benefits that we would get from such an expedition, the planning and the moving ahead on this, we can just begin to understand some of the benefits that we would get as a population for people who don't go there, but we have seen a lot of technological innovation as a result of the whole space program.

I wonder if we could just think 50 years ahead of what this could mean to the average person who may not get to Mars but some of the benefits that could possibly occur. Does anybody want to speculate on what that might be? You have been very visionary today.

Captain CERNAN. We can talk about the technology from the Apollo. We can talk about the timing of Apollo. It came in the turbulent sixties, when we were involved in a very unpopular war, campus crime, civil strife. It gave this country something to hold our head high about. We were being blown out of the water by Sputnik and by everything the Soviets were doing at that point in time. Those are all benefits from Apollo.

But I think, personally, we may not know for another 50 or 100 years the true significance of having first left this planet during Apollo and called, as I said earlier, even for a short time, valleys on the Moon our home. I think it is going to take that long to look back.

I am not sure that it wasn't 100 or more years before the people on this continent and around the world looked back at the significance of what Columbus did back in 1492. Certainly they didn't know 25 years later the importance of his commitment. I don't know that we yet know the importance of what we have done. I don't know that we yet know the challenge that JFK gave us and whether he was a dreamer, visionary, or just politically astute. Maybe he was all three. I would like to ask him, if I could, today.

Mr. DAVIS. Dr. Aldrin, do you want to add anything? You have been very good about talking about how possible this can be, laying out a plan for Mars, which I think is great. But we get asked the question, given competing priorities, what does this mean? And so maybe we have no idea what it means.

Mr. ALDRIN. Let's look briefly at maybe what was the value of going to the Moon. In the last 27 years, one thing has stood out that, as I meet people, they want me to know where they were when we were on the Moon, and they remember vividly that particular day.

And they are almost obsessed to come up and tell me where they were. And I am trying to understand what that means, and what it means is that there was value added to a human's life on that day, and I multiply that by the millions of people that experienced that, and I think we are getting closing to understanding the value of human society challenging itself and carrying out a commitment successfully.

It's not the value of the rocks that were brought back or the great poetic statements that we all uttered. Those things aren't remembered. It's that people witnessed that event. And we are not going to justify going to Mars by what we bring back. Whether there was life or was not life shouldn't be a determining factor whether we go to Mars. We are going to make a commitment and carry that out.

And what is that commitment going to do to this world today that is so focused on the immediate payoff, what's in it for me right now. Everything around us, fed by the communication industry, focuses on fixing today, today, and it doesn't focus on where are we going to be in the next 20, 50 years. We need something that draws away from today, and internationally supporting a striving settlement on Mars and all the benefits that is going to bring back here on Earth, and the feel-good attitude that people are going to have, that's going to be the value of going to Mars.

Mr. DAVIS. Thank you very much.

Mr. Weldon. The gentleman from Texas, Mr. Turner.

Mr. TURNER. It is exciting just to listen to you speak. I guess as I listen to you lay out your vision, Dr. Aldrin, it seems to me that one of the biggest challenges we face is trying to figure out a way to get that common commitment, and I would be interested in any of your suggestions.

It seems to me that space exploration is much more complex, with many more options than there were back in the 1960's, and perhaps it is a little bit more difficult to frame the goal, the mission that we need to be pursuing. Obviously, it takes leadership from the top, and I think that your suggestion that you hope that a President, after the turn of the century, would be leading and enunciating the mission, is important.

But it seems to me, and I am certainly not one who is enamored with blue ribbon commissions, but it seems to me that there has to be a collection of the scientific, the commercial community gathered around a table somewhere with a charge delivered by a President or a Congress to say, lay out for us what you think the mission ought to be, what the objective ought to be, what the pathway is that we should follow, and to do it in a way that the net result has credibility with the American people, with the Congress, and that we could use that to put this issue at a high enough profile level that people would begin to understand that this is where we need to go, this is where we should go, and we could once again begin to be excited about the fact that we are exploring the outer limits of the universe.

Am I off track here? Have you all done this? Have you seen this happen? Has it not given us the momentum we need, or would it be helpful to urge the President and Congress to say we need to gather around a table, a blue ribbon group, to define the mission, to reach an agreement?

For example, Dr. Aldrin, as I heard you make a presentation, I wondered if Captain Cernan and Mr. Carpenter agreed with you, would this be the mission they would lay out, as you have laid it out in so much detail? Is there a need for some consensus building here and some need to elevate the profile of what that consensus is?

Mr. ALDRIN. Each year as we approach New Year's Eve, people make resolutions. We are coming up on millennia. I think we should consider resolutions for the next century: Where would we like this Nation to be as we move through the next century.

I think as you look at the dates, even going from 1999 to 2000 is a big change. I think we could use the year 2000 as a national discussion time period along with the political discussions that are going to be going on the same year, and look at the alternatives, look at what our resolutions maybe ought to be and bring in the public.

I think that space, the people want to journey into space; they want to share that participation. Just ask them. I go around and they want to know when they can get into space. And it is do-able. The tourism industry worldwide is a multibillion-dollar industry. Let's just unleash that into space, and not just for the affluent, but wisely worked out lottery principles. You can form a corporation and issue shares and distribute the dividends by random selection for thousands of space-related prizes, including a ride into orbit. And that could develop the rocket and the spacecraft systems needed to go to the Moon. Not the other way around. We are not going to make a commitment to go to the Moon and then use those vehicles for tourism; it should be the other way.

Mr. TURNER. Do you view, Captain Cernan, the future of the space program the same as Dr. Aldrin or do you have different views?

Captain CERNAN. Well, we have different views along the way, and Buzz is certainly an expert on techniques and approaches and boosters, and I am more of a dreamer, a philosopher.

I think you have to have the desire to want to go, to do something that hasn't been done, something unique. Probably a lot of people in this room and up there with you are not going to like this comment. I am not sure I do, either. In the space program that we are involved in today, I call it space exploitation. The shuttle, perhaps one of the most sophisticated flying machines ever built and flown, the space station because of its international nature is going to be significantly important to the future. The space program today is not exciting to people. It's not exciting to kids. We have been to the Moon 25 years ago; we went to another planet. You have got to define what it is to voyage or journey in space.

I've been in orbit on Gemini, it's spectacular, my first flight. Do I want to go back to orbit, no. I have been to the Moon twice. If I am going to go somewhere, I am going to go to Mars. That's me. Perhaps that is selfish. But until *Apollo 13* came around and exposed people who were around to remember, and young children, to what space journey was really all about, there was little or no excitement about it.

Now when you talk to kids—their window was opened. Why don't we go back? Why didn't we continue on? When are we going to go to Mars? When you talk to young kids today, and that's really the grass-root support, they are not satisfied to just go around in circles anymore.

What we are doing today is significantly important, economically and otherwise, in the exploitation of space. But we are exploiting space through the shuttle and space station at the 100 percent cost of exploring space. We ceased to explore space when I left the surface of the Moon and we haven't explored space in 25 years, at least under my definition. That's what excites kids. Star Trek, Spaceship Enterprise. The concept is if it's a space station, it ought to go through a black hole. I don't want to get too far out, but that's what gets kids' imagination. That's what gets them to ask questions and want to know more.

Perhaps I didn't refer to it, and I know most of you are interested in education, perhaps one of the greatest and most untapped resources of Apollo itself was the stimulus to education. The motivation that you can see resulting in the hearts and minds of young kids who want to talk about the Moon, what is it like on the Moon.

So, I think we have two different space programs. One is a program we are involved in now, shuttle, station; and the other one is the space program of exploration which we only talk about, which doesn't exist today.

One of the unique differences about Mercury, Buzz and I both flew in Gemini and Apollo, each of those flights were interdependent on the other. The three programs were a program. Without Mercury, there wouldn't have been Gemini. Without Gemini, there wouldn't have been Apollo. Without any one flight in those programs, the next flight wouldn't have existed. If I hadn't gone to the Moon on *Apollo 10, Apollo 11* would have been a totally different story.

Today our program, it's the nature of the program, not necessarily a criticism, it's the nature of the program, every flight today with the exception of those that will be put together to assemble the station is an individual event. You can cancel it, change, slip it, move it around, refly it, and the doesn't affect the follow-on flight to any extent. So we are in the mode of exploiting space.

We have a highly sophisticated research vehicle in a shuttle, and what I think we are doing now is correct. I think we are headed down the right path. I think we need to develop that international space station. I think it's ultimately important, scientifically, technologically and perhaps more importantly from an international point of view. But again I say we are doing it at the 100 percent total cost of ignoring exploration.

Mr. CARPENTER. Mr. Turner, I think the answer to your original question is difficult to come to because the most important problem we have is arriving at a consensus in forming the answer to your question. That's the most, the difficult and most important.

Mr. ALDRIN. There was a wonderful study done by a wonderful person who led NASA when we first landed on the Moon, Tom Payne. It was called the National Commission on the Space. I think if you look at all the studies done before and after, that will stand out.

So as we approach this millennia change, I would encourage people to dust off that pioneering, the space frontier study that was done. The timing was atrocious. It was just about to be submitted when the *Challenger* accident occurred.

Captain CERNAN. Buzz hit it a moment ago, what's in it for me now, what am I going to get back, why should I go to Mars, what am I going to get out of it, what's in it for me. It's a lack of our futuristic instincts to look into the future. What's in it for our kids? I am not sure I can tell you that, and we seem unwilling—I hate to be one of those guys that says you should have been here last week, the fishing was great, but if you look at how Mercury, Gemini and Apollo evolved, we took risks, we think we managed our risk pretty well, that I am not sure we have the gumption to take today.

If JFK stood on the steps of Congress here today and said we are going to go to the Moon, I don't believe we could get there in a decade. I don't believe our mentality would allow us to do what we did a generation ago. I think that is one the major problems. We just seem to be unwilling to commit without a guarantee, and there are no guarantees in this life. For you or for me or for space or for anybody. And that's a culture that has slowly evolved over the last 25 years, at least having raised a few kids in this generation who admittedly could tell me the same things, it's something I have observed.

Mr. TURNER. Thank you.

Mr. Weldon. I would like to recognize the distinguished lady from Maryland, Mrs. Morella.

Mrs. MORELLA. Thank you.

I note that President Clinton used that concept of we want to go on the Moon, we want to find a vaccine for AIDS. It has become legendary because it shows the can-do spirit of America.

I think it is a shame that you say that practically we may not be able to achieve it going to the Moon or now going to Mars, and I wanted to point out a few things. For instance, when we are legislating and coming up with appropriations, as well as authorizations, we always have trouble with space and the space station for the very reason that you mention, Captain Cernan, it is what are we going to get from it; are we going to be able to have a reliable partnership or are the Russians going to back out because they don't have the money and we are going to be stuck handling it; what are the benefits going to be.

I am interested in the papers you have submitted. The whole concept of space tourism, the fact that you envision within 20 or 50 years, and we better do it in 20 because I don't think I will be here in 50, that we could have colonies on the Moon or Mars, and we could have shuttles going back and forth, I wonder if you might elaborate on that a bit.

I do, as a backdrop, remember a number of years ago I was one of the people that submitted a bill against Mylar billboards in space. Do you remember that? You could be up there in space and you see this big billboard "Drink Coke" or "Buy Nike Shoes" or whatever, and there was a company that actually had considered doing that and we introduced legislation. That may have been one of the deterrents for something like that. But how do you see this space tourism? Also, something, I hate to use that word with you, with the three of you, that is affordable.

I will address each one of you, if you want to make any comments on that. Do you really think we will be able to afford to do it and would it be a practical kind of thing to do, as well as visionary?

Mr. CARPENTER. I think it's a definite possibility and something we should pursue, but after the fact. I am more interested in the search for new truths, and if space tourism falls out of that search, that is fine, but that in my mind is not the end of the project. It is an artifact.

Mrs. MORELLA. You are interested in, what did you say? Space——

Mr. CARPENTER. I am dedicated to learning how to fly to Mars and return safely, and much will fall out from that, from the conduct of that exploration.

Mrs. MORELLA. Many, many other benefits, obviously true. Thank you. Captain Cernan.

Captain CERNAN. I have a comment on two things. I also heard about President Clinton's commitment to find a prevention for AIDS in the next 10 years and I think it's an admirable commitment. Whether it be AIDS or heart disease or cancer, we would like to find preventions and cures for all of those things. But the facts of life are finding cures for those things does not excite people, young and old, like watching the Star Trek movie, like finding a potential of life on Mars in a piece of meteorite or like going to the Moon like we did on Apollo. So I think it's difficult to compare JFK's commitment of going to the Moon in a decade in terms of the response it got from people, even the disbelief, compared to solving some of the ills that need to be solved in this world. There's a lot of them and they are admirable.

I am out there talking to kids. I know what gets them excited and gets them involved. People young and old, they ask what does it look like, what did it feel like, were you scared. We get this all the time. And you don't get the same kind of questions if you talk about finding a cure for AIDS. I am sorry, it just doesn't——

Mrs. MORELLA. I think you mentioned it just to show the can-do spirit. We did it for that because we had a mission. And I must say, as someone who has been on that space commitment for many years, I really think after that we lost that real mission, the sense of working together.

Captain CERNAN. Absolutely. Let me be a dreamer for about another 30 seconds and go beyond what Buzz said. I don't care what motivates us to Mars, I don't care—if we saw a little green man sticking his head up several years ago when we sent Viking to Mars, we would be there by now. I don't care why we go. If it's tourism, that's fine. Science has never been a motivator. It always runs piggyback. It was not the reason we went to the Moon; it will run piggyback when we go to Mars. So whatever it is, if it is tourism, which seems relatively exciting to me, Buzz, I don't care what it is.

But my dreaming mentality, and none of us will be around in 100 or 200, some day—I am second generation American. I can remember my grandparents talking about coming over to the new world from the old country. I can remember them talking about always wanting to go back to the old world, to Europe, to their birthplace. At some point in time, Mars and Earth are going to have that relationship. In 100 or 200 or 300 years, those who follow us will come back to Earth to see where their ancestors came from, and there will be space transportation and there will be tourists who go to Mars and come back to Earth. And it's an easy prediction because, no one is ever going to call me on it, but I believe in the next couple hundred years you are going to see that kind of relationship.

Mr. ALDRIN. Let me take us back a few years, like the mid-1920's, people were traveling across the Atlantic in a ship, until someone said, maybe if we had a prize, people would compete, be motivated to compete for that prize. Charles Lindbergh won that against a number of other competitors.

We are trying to do the same thing today with an X prize for suborbital flight. But that exercise of Charles Lindbergh arriving in Paris, electrifying the world, opened up transatlantic air travel and brought about the need to do that better and faster and jet travel and now let's people take vacations doing that.

The reason that we want to do tourism is to reduce the cost of access to space by having volume traffic. We want to develop the kinds of spacecraft and rockets that are going to get to space and then produce lots of them. And people aren't getting any smaller. Satellites are getting smaller and smaller but people aren't, and people want to get into space. If it is $100,000, thousands of people want to do it. Should we turn our backs on them? Well, there is probably going to be a little bit of government money in that rocket and spacecraft system. Let's open it up to the people.

I can't understand why people invest in the lottery but they do, and they get excited about it. They put up a little bit of their savings in hopes of a windfall, and that's exciting and it opens the door.

You are going to hear from a wonderful gentleman in the next panel and I think he will excite you about privatizing, unleashing the private sector into the space frontier, and tourism is going to be what opens it up.

Mrs. MORELLA. Thank you, gentlemen. Thank you, Mr. Chairman.

Mr. Weldon. Captain Cernan, you were the last man to leave footprints on the Moon, I understand. Do you have any special feelings about the significance of that that you want to share with us?

Captain CERNAN. I get asked a lot, how do you feel, how do you feel about being the last man to have walked on the Moon, how do you feel about having left the final footprints from Apollo. And, of course, just to have had the opportunity, it's very unique and I am very proud to have done that. But there is always going to have been one human being who was the first to step on the surface of the Moon, and we all know who that is. But there is going to be many, many last human beings to walk on the surface of the Moon. I just have held that distinction for far longer than I ever thought I would. And I can say on top of everything else, it's somewhat disappointing that I can sit here today, this December will be 25 years, and I still carry the distinction with pride but with disappointment at having been the last man to step on the surface of the Moon. Certainly at least through the end of this century.

Mr. CARPENTER. May I add that we are all proud to know Gene Cernan, the last man to walk on the Moon, but we would be even prouder to meet the next man on the Moon, and soon.

Mr. ALDRIN. Let me make an observation. If we are discussing a commitment of whether we are going to go to Mars and not commit to settlement, to increasing settlements, let's not even bother going. You can't go there once, twice, three times and then say I am going to call this off, we have done that. It has got to be a commitment to a growing expansion outward and settlement, and if the Congress isn't willing to do that, then we will get the American people to maybe get us a new Congress.

Captain CERNAN. Dismissed.

Mr. Weldon. Let me move on to another line of questioning. I represent the area of Florida called the Space Coast, Brevard County. I know all three of you, gentlemen, are familiar with that area. You may not have lived there but you have blasted off from there. Every time a shuttle goes off, I say a little prayer knowing that the area was very badly devastated by the loss of the *Challenger* and grounding the shuttle fleet for 2 years and the economic impacts that had.

One of the things that I have gotten into discussions with some of the leadership within NASA and on the Space Subcommittee and the Science Committee is what would happen to our manned space flight program if that were to happen again. Do we have the will and resolve to hang in there and continue in manned space flight? Now, I don't think it will happen again. I think we have gotten the bugs out of the system and we will continue to fly the shuttle safely, but can we continue to have a manned space flight program in the setting of another disaster like another *Apollo 1* setback? We got through *Apollo 1,* we got through the *Challenger,* but do we have the national resolve to move on ahead and continue our manned space flight program?

Mr. CARPENTER. Well, that deals I think with what was said earlier. We are in this business and we are in it because we know that the benefits are worth the risk. The answer to your question is to be found in whether you and the rest of the Nation are aware of that simple fact as well.

Captain CERNAN. *Apollo 1* was every bit as devastating, maybe not in total loss of life, but to the potential of the space program as *Challenger.* We hadn't even gotten an Apollo spacecraft off the ground and there was a fire. Three human beings lost their lives on the pad. We were in a race with the Russians, JFK's challenge to get there by the end of the decade. We recovered from that accident. We recovered. The accident occurred in January 1967 and we recovered and were airborne on that first Apollo flight in October 1968. And within 7 months Buzz walked on the Moon.

Apollo 13 occurred in March. The following January—*Apollo 13,* truly, truly—I was backup commander on *Apollo 14.* I was working very close on that flight to bring these guys back. We truly came closer than we knew then to losing those guys in space.

We sent three more men and four more flights into the same realm of outer space to complete, to finish the job that we called Apollo. We recovered in, what, 8 months, 9 months.

The *Challenger* accident was devastating and of course the whole world saw it, that made it even worse. And we lost seven people. But there isn't a person on that flight that got into that spacecraft that didn't volunteer, that didn't know the risk. I was close to that one, too, because I was on the selection committee to pick those school teachers. It took somewhere between 2½ and 3 years to recover from the *Challenger* accident, and I think we have not yet totally recovered from that accident today.

Quite simply, the answer to your question is as devastating as *Apollo 1* was because there were people at that time that said quit, we don't need to go to the Moon, as devastating as it was, I think if we had another accident today, our entire Nation's space program, again because of something that is lacking, maybe it is commitment, maybe it is willingness to take a risk, whatever it is, would probably come to a screeching halt for some indefinite time in the future, and it would have to probably, probably gear up again and start all over again a decade or two down the line. I honestly believe that that could be the result of another accident like *Challenger.*

Mr. Weldon. Dr. Aldrin, do you have anything you wanted to add to that?

Mr. ALDRIN. We probably had with the *Saturn 5,* first and second stage: a two stage, fully reusable launch system. Instead of doing that, we started with a clean sheet of paper and defined a two-stage airplane, an orbiter and a booster, and we put a cockpit in the booster that was not needed. We overpriced the system, had to redesign it, and then the funds were cut back and that resulted in what Werner Van Braun said we should never do and that is launch human beings on solid rocket boosters.

After the *Challenger,* we decided to improve the solid rocket booster. If that booster is so good, why isn't it being used on something else? Why isn't it being used to replace a Titan?

A solid rocket blew up on the Delta recently. There are problems. We may not have a next generation that we are reaching for because we may be reaching too far with a single stage. We may have to live with the shuttle for a long time. I am really worried that we don't have the resiliency in our system. We don't have a backup to the laboratory, we don't have a backup to the HAB module on the space station. We had a problem designing the node and now the nodes are being built in Italy. Why is that? That is not the way our space program was back in the 1960's and 1970's. There is not much resilience in what we are doing. We need more volume; we need a bigger fleet. Tourism will bring you that bigger fleet, and the people aren't going to fly on solid rocket boosters.

Mr. Weldon. Thank you. I would like to see if we have desire for a second round of questions.

Mr. DAVIS. Let me just ask a couple. I don't know if my questions are any good but the answers are outstanding.

I think sometimes we try to design an inexpensive space program up here with so many competing activities it doesn't get—because you can't realize the immediate benefit, as you put it.

People, Members sometimes, and the public like things quantifiable, and I think, Dr. Aldrin, you put it very well when you talked about society challenging itself and succeeding and how we need that. Some of the most important things in life are unquantifiable. The commitment we can get from NASA would do. America needs that right now.

The program right now has in some way turned into a foreign aid program, the way it is constructed. So I think what you are saying—I would also add whatever you end up doing, when we define a mission and go after it again, we are not going to come up with a dry hole from a scientific point of view. The inventions that come out of this that have applications every day are significant and they are helping us treat diseases, they have made the computer, you know, everybody can own a hand-held computer and calculator, and these things would not have been possible without the space program. So it is very inspiring to hear what you are saying. I think we need to involve the private sector more and I think we will hear more in the next panel about ways of doing that, and also on the Space Subcommittee, which I am a member of.

I just wanted to know if you would like to amplify on that, and recognizing that all endeavors that government is involved with, we are finding that government alone can't do it; we can reply on the market system to produce things more efficiently and better and whereas government by itself, not by intention, just ends up being a very inefficient vehicle.

Any comments on that or thoughts?

Captain CERNAN. I think the programs that interact in terms of privatization, if that's what you are referring to, I don't think there's any question. I don't think there's any stopping it. I think it's going to continue to happen, but, you know, the government has always been the high-risk element of research and development. There is no—the entire aerospace put together could not have afforded the risk of going to the Moon on Apollo. It has to be the government, so the government has to take the lead and be out front and be willing to be the tip of the arrow, but bring in the private sector wherever and whenever possible. And I think you are going to see more commercial value come out of space.

NASA, over the last several years has done a terrible job of developing a people awareness. People talk about the money and you fighting for bits and pieces of money here. First of all, it is ludicrous that something as objective as exploring space should compete with HUD and VA, that is ludicrous, but that's in your ballpark, not mine.

But you talk about billions and billions of dollars, and the average person on the street doesn't have the vaguest idea of what $1 million is much less $1 billion or $10 billion. But if you start telling them about the space program, but why does it have to cost so much? How much does it? If you tell them the space program costs 1 penny out of each tax dollar, people can't believe that. My God, I have more fun watching it on television, it costs me 1 penny out of every Federal tax dollar to send you guys to the Moon? Yeah, and it cost 1 penny out of each to watch the space shuttle going on. They can identify with reality like that.

We have done a terrible job, we NASA. We are as much at fault as anybody. Nobody can understand and relate to the technology and all that fancy, wonderful stuff that's important and we get benefits from, but they can relate to things they can identify with, and how we spend their dollars is something they are very, very appropriately concerned with. We need to develop a broader, grass-roots space awareness program, quite frankly, and maybe that's NASA's responsibility.

Mr. DAVIS. It is interesting you say that. Then you tell them almost 20 cents of every dollar is going to pay interest on the national debt, they get really mad.

But Dr. Aldrin, you wrote a Ph.D. thesis back in the 1950's about what might have then been a wild idea of spacecraft rendezvousing and going round and round. It is very intriguing what you talk about, sending people to Mars and who knows where that will lead. I think it is timely since we are not having a mission to Mars now with robots and sending them up and it's a good time to rekindle this debate and discussion.

Mr. ALDRIN. I think we should not be afraid to learn the lessons of the past. We had within the *Saturn 5* rocket the next generation shuttle system, but we didn't do that. We started all over again with the clean sheet of paper and have the aerospace companies recompete to see who wins this time. We have got a space station that is going to go up and it's going to take about 50 launches, including the supply flights in 5 years. We launched a space station with the Saturn called Sky Lab. It took one launch. If we launch another space station in the future, it better not take more than three launches or it's not going to survive.

You have seen the trouble we have had justifying this type of a space station that is assembled by the capacity of the space shuttle. We need bigger capacity to put up hotels. Call them what you want, but people are going to go there. This is the NASA budget. I think everybody has to understand——

Mr. DAVIS. What's left of it.

Mr. ALDRIN. That that's what is happening today.

Mr. DAVIS. Thank you very much.

Mr. Weldon. Mrs. Morella, do you have any other questions?

Mrs. MORELLA. No, thank you.

Mr. Weldon. I guess the only other question I would like to ask the panel, we have talked a little bit about how times were different in the 1960's. We had the Russian challenge, one of the issues that I think plays a role in this lack of willingness or commitment perhaps or a level of commitment perhaps today is just the basic economic problems we are having here in Washington, DC, and I don't know if any of you would care to comment on that issue, but we do have a $5 trillion debt, we are making headway to balancing the budget, and it is projected that the deficit for fiscal year 1997 will be at about a 15 or 18 year low, getting down to perhaps less than $100 billion.

I believe at the time when you were enrolled in the Astronaut Corps, the national debt was a fraction of what it is today and the range of about a tenth. I believe that the expenditures on entitlements were in the range of about 10 percent of Federal expenditures or 15 percent of Federal expenditures.

Do you see any correlation between getting our economics in order and having the willingness to explore, to make the investments necessary to explore? Is this a factor in your vision or do you feel that this is just a lack of will that is not related to the basic economic problems our Nation faces?

Mr. CARPENTER. I think it's a lack of will and it might be also a lack of clearly defined and clearly appreciated acceptable goal.

Captain CERNAN. You gentlemen, ladies and gentlemen, and pardon me, Mrs. Morella, I tend to use the word "mankind" very generically so I don't mean to exclude, but I have been called on a couple of times, and you might have caught me today, but I do use it generically. You ladies and gentlemen are practitioners. We can sit here and dream and philosophize, but we still have to pay for it.

I go back to what I said about space awareness, what the real costs are. But, you know, I think back in the Apollo days, we probably had, the deficit may have been lower and so forth, but I think basically we still had the same problems. We had people saying, why do you want to waste all that money going to the Moon, we have all these poor people here to be fed and there is always—money didn't get us to the Moon and money is not going to find a cure for AIDS and cancer and money is not going to solve poverty. People are going to solve it. Ideas, commitments, obviously with this practical use of money.

The money that was spent was and has being spent in space comes back to us tenfold, even to the extent that we don't appreciate it. When you look at the technology and the industries that have grown and the computers, if you could take any one of those dollars spent in 1960 to send us to the Moon and could possibly have tracked to this date 25 years later, the phenomenal return on that dollar investment would probably blow all of our minds. I don't know what it would be, but I do know the investment is minimal. As I say, 1 penny out of each tax dollar comes back at least tenfold.

And I go back to people's awareness and interest and excitement. I think if people really understood how little, not how much, how little it costs to continue building and growing this foundation of technology and the return from that investment that people, that we all take for granted today, in our hospitals, in our schools, classrooms and our homes and our factories, if we really understood all that, you would get so much grass-root support you ladies and gentlemen up here in Congress could not afford not to put a program together to further that effort, to take us to Mars, quite frankly.

We just, the average person on the street has got so many other problems. They have got to send their kid to college, the grandchild just skinned their knee or whatever it is, their job is a little insecure, and so those are the things that are important to them. But if you could bring what the space program does for them down to, quote, their level of understanding, economically, I think you would see a grass-roots support that could not be stopped.

Mr. Weldon. Thank you.

Well, I want to really thank all three of you for coming and being here today. If I could quote or paraphrase Mr. Davis, I am not sure our questions were great, but your answers were wonderful, and I want to thank you very much for your testimony. I know that we are looking and searching for a new direction and a new level of commitment, and your coming here and being here is really a tremendous help to us.

I would like to now dismiss you and invite our second panel to come forward.

Mr. Weldon. If you would all please rise, we need to swear you in.

[Witnesses sworn.]

Mr. Weldon. Let the record show that the witnesses responded in the affirmative.

Now I would like to formally welcome our second panel. Our first witness to my left is Mr. Joshua Ouellette. He is a 15-year-old student at the Academy of Science and Technology in the Woodlands, TX. He is studying superconductivity and has already sold an invention to a manufacturing company. It is also worth noting that he aspires to be an astronaut.

The next witness is Dr. Robert Zubrin. He is president of Pioneer Astronautics, an aerospace research and development company. He is the inventor of several unique concepts for space propulsion and exploration, the author of over 90 published technical and nontechnical papers in the field, and was a member of Lockheed Martin scenario development team charged with developing broad new strategies for space exploration. He is also the author of the book, "The Case for Mars: How We Shall Settle the Red Planet and Why We Must."

The next witness is Mr. Tom Rogers, an expert in Near-Term Commercial Space Transportation Opportunities and Technologies and a familiar witness to the Space Subcommittee on Science.

Next, we have Dr. Seth Potter. He is a scientist, visionary in solar energy from space and professor of Applied Physics at New York University. And Dr. John Lewis is a scientist, author, and expert in astrology, astrogeology and the study of off-earth resources.

We thank you all for being here today, and we would like to begin with Joshua. Please try to summarize your comments to keep them to the 5-minute time limit. Thank you.

STATEMENTS OF JOSHUA OUELLETTE, STUDENT, ACADEMY OF SCIENCE AND TECHNOLOGY; SETH POTTER, PROFESSOR OF APPLIED PHYSICS, NEW YORK UNIVERSITY; BOB ZUBRIN, PRESIDENT, PIONEER ASTONAUTICS; TOM ROGERS, NEAR-TERM COMMERCIAL SPACE TRANSPORT OPPORTUNITIES; AND JOHN LEWIS, ASTROGEOLOGIST

Mr. OUELLETTE. Good morning, Mr. Chairman, committee members, and distinguished scientists and astronauts. My name is Joshua Ouellette. I have been asked to speak today as a representative of all the young people in this country who are aspiring to one day participate in the American space program.

First, my thanks go to Mr. Robert Charles, Mr. Mobly, Mrs. Christover, Mr. Scott Carpenter for their work in allowing me to speak to the subcommittee on the work I feel so passionately about.

At present, I am attending the Academy of Science and Technology in Oakridge High School, in Conroe, TX, where I am enrolled as a ninth grader. The Academy is a magnet school for those students who show particular interest and ability in math, science and technology.

I am also currently a cadet in the TX–951 Air Force Junior ROTC Cadet Corps at Oakridge High School. I currently hold the rank of cadet staff sergeant with the positions of Information Management NCOIC and Kitty Hawk Air Society War Eagle chapter president. The KJS is usually described as the ROTC version of the National Honor Society.

I am also a life scout of the Boy Scouts of America, Troop 1772, with the position of assistant senior patrol leader.

I have been asked to speak mainly on my own thoughts of the past, present, and future of our Nation's space program. Hence my statement is far more opinion than fact, such as those that will be covered by the other people testifying here today.

My views of space are deeply rooted in every fiber of my consciousness. When I was only 4 years old, my parents had to make a deliberate effort to keep me away from the television set so I wouldn't be upset by the *Challenger* explosion. Even at that early age, such events affected me on the deepest levels.

My interest in space exploration has been inspired by both space history and science fiction. The first steps as to traveling between the stars have been taken through Earth's immediate neighborhood. Those travels have produced beautiful images from the Mercury, Gemini, and Apollo missions, clear up to the shuttle missions and Hubble telescope. The incredible pictures have inspired a desire within me to see these magnificent sights with my own eyes, the lunar sky with the Earth looming in the background, the great nebulas of swirling and glowing gas, and the Milky Way looking solid white befitting its name.

The goals I have set for myself are exceptionally high, indeed, aiming for the stars. It would be the highlight of my existence to be remembered as one of the first to step foot on Mars. Even riding the space shuttle of one of its future counterparts would be fantastic. If I apply myself at school and in Scouts and ROTC, I hope to increase the odds of making these dreams come true.

However, my chances of reaching these goals are in no way completely under my control. An individual working by themselves cannot make it into space. It requires a nation backing that individual. Space exploration is probably the greatest investment of all-time, and at present there is only one nation that can make that investment, the United States of America. If our Nation can put a colony on Mars, a base on the Moon, or even a space station in orbit, the benefits would be great. In time, not only on scientific values but also the economic values would present themselves. There may be a limited amount of raw materials on Earth, but the supplies of space are nearly infinite and have never been tapped.

Many people feel the reason we have not walked on the Moon in decades nor gone to Mars is best explained by the reason we ever built the space program in the first place: Our Nation responded to a perceived threat from the Soviet Union. It wasn't just the fear that made us make the effort to land on the Moon, but it was that something suddenly appeared for the entire Nation to rally behind. No nation has ever accomplished any great feat without rallying behind a cause nor have ununified nations ever lasted for any great span of time.

Right now our Nation has no great rallying call such as President Kennedy's call to place a man on the Moon or even the revolutionary call for freedom that built our Nation. The result is a loss of national camaraderie and unity. "Ask not what your country can do for you but what you can do for your country" is in danger of regressing. In other words, we have become a slightly un-unified society. The solution may lie in the space program and the solution to the space program's dilemmas may likewise lie here. We must all rally behind something, and the space program needs someone to rally behind it. This is obviously easier said than done.

From here the next step would be to continue on the present path, developing the technologies necessary to move our space program along with the completion of the X–33 new generation space shuttle. The sooner this is done, the better. This major accomplishment will be of interest to the Nation.

The completion of the international space station could also spark this interest. A series of such accomplishments in quick succession will buildup a large amount of support. The greatest rally would be a mission to Mars. If done quickly and with deserved fanfare, this act would bring the Nation together in a way equalled only by the Apollo missions.

The United States of America is the greatest Nation of all times and is more than capable of the greatest feats of all time. It will take that one spark to set us in motion and so many other problems will be solved.

Every one has heard of the scientific and even economic benefits of going into space. We have all heard of such successes as Velcro, Teflon, Tang, communications satellite networks, and advanced computer technologies. More will come, but perhaps something far greater may be a benefit, a deeper understanding of ourselves and our humanity.

I thank you for the consideration of my testimony.

Mr. Weldon. Dr. Zubrin.

Mr. ZUBRIN. Thank you. Is it possible I could have the lights down about halfway. I am going to talk from over here, if it's OK with you.

Mr. Weldon. If you can talk loud.

Mr. ZUBRIN. I can talk real loud.

We have had a lot of speakers this morning who generally are discussing why it's important to us to launch a major new initiative in space, and I feel, especially in accordance with comments made by Mr. Cernan, I am going to direct most of my comments to not why we need to do it, but to make clear the fact that we can do it, we can have humans on Mars within 10 years if this country can muster the will today.

There's a lot people saying it can't be done, it's a task for two generations from now. That's not true. One reason why people believe it can't be done is they have been shown ways to do it that are impossible, and, for example, this is what happened when George Bush made the call for a Space Exploration Initiative in 1989, NASA came back with a 90-day report, they said we can do it in 30 years if you give us $450 billion, which you know how well that went over, end of story.

Well, the reason why it was so expensive and such a long-term proposal was what they came up with was concepts like this. Build giant spaceships in space, constructed in orbit in a set of orbiting hangers and spaceports and so forth, an assembly of capabilities that would take a couple of generations to create and whose primary benefit would be that it would employ a lot of people developing all this hardware and technology. But it would not get you to Mars any time soon and for any kind of cost that anyone was willing to contemplate.

The fact is going to Mars is not that hard. You don't need to build giant Battlestar Galactica spaceships to do it. You do need a heavy lift vehicle. You could use a *Saturn 5,* or we could create an equivalent to a *Saturn 5* very easily out of shuttle technology. It's not that hard a thing to create, built in the 1960's. We can have another one based on shuttle components based on 4 years from today if anybody turned on the switch.

Now, you have got a heavy lift booster with roughly *Saturn 5* capabilities. How do you use it? OK, you use a two-launch scenario. This is known as the Mars Direct Plan, which I developed when I was working for the Martin Co. doing planetary mission design.

The idea is the following: In a given year, I call it year 1, call it 2005, you launch one of these boosters off the Cape and you use it to throw to Mars an unmanned payload weighing about 40 tons. It takes 8 months to get to Mars, it lands on Mars. What is it you have landed on Mars? OK, it's your Earth return vehicle. What's the Earth return vehicle? It's a little rocket ship that has a small cabin with Spartan quarters for a crew of four people for a 6-month voyage back to Earth.

The thing has two unfueled chemical propulsion stages below that, and below that, not shown in this picture, you've got a nuclear reactor mounted in the back of a light truck. You land this thing on Mars, you tell the robots to drive the truck a couple yards away, put the reactor on the ground, switch it on, now you have power to the ship. And what you do is run a pump and you suck in the martian air. Because you send this thing out to Mars unfueled, and this is the trick. When you go to Mars, you don't bring the fuel with you, because Mars has got an atmosphere which is the ideal feedstock for making rocket fuel. Bringing rocket fuel to Mars is like bringing oil to Saudi Arabia, it makes no sense at all. In fact, it's a lot dumber because it's more expensive to bring rocket fuel to Mars.

You run a pump, you suck in the martian air, which is carbon dioxide, you react that with a little bit of hydrogen you bring with you from Earth, and you turn it to methane and oxygen. Methane is not the greatest rocket fuel. You store it in your tank. The water you take is split into hydrogen and oxygen. We store the oxygen, recycle the hydrogen, round and round we go, it's 19th century chemical engineering. It's not just something you can write down on equations. Actually, the technology has been around for 100 years, but when I was at Martin we built the machine.

This is a full-scale unit you are seeing here. It cost us $47,000. You know what $47,000 is in a major aerospace company, that's how easy this is. That's nothing.

So now you have got a fully fueled Earth return vehicle sitting and waiting for you on Mars. Once that is done, then at the next launch window to Mars, and your launch windows to Mars occur every 2 years, so if this launch occurs in 2005, here we are in 2007, you launch two more boosters off the cape.

One sends out another Earth return vehicle with nobody in it and the other sends out the crew. They don't have to fly to Mars in the Battle Star Galactica, they just fly to Mars in a simple adaptation module, like an oversized tuna can fitted out with space station life support type equipment. It has a crew of four. It's got two decks, each with 8 feet of head room.

The upper deck is where the two could live, the lower deck would probably be more of a cargo hold. Here is the upper deck with a stateroom for each of the astronauts, an exercise area, a lab and a solar flare storm shelter. A lot of people make a big deal out of solar flares. You can map out solar flares with 5 inches of water or provisions which you have on board the ship in any base.

Now you can also create artificial gravity on your way out to Mars by just tethering off the HAB off the upper stage of the booster that threw you to Mars, that is coasting off of Mars, too. You spin this up, you can create gravity and avoid effects of long-term zero gravity exposure and that is my preferred way to fly to Mars.

However, you should know that, look, we have gotten a lot of false data from the Russians on the idea that 0–G countermeasures don't work. For the past 15 years we have been seeing cosmonauts come down from MIRE and we had to take them off on stretchers. But here, Shannon Lucid walked off the shuttle after 6 months in orbit. Six months is how long it takes to fly from Earth to Mars. Shannon spent that long in space. She walked off the shuttle. Here she is walking around Johnson Space Center the day after she landed, shaking hands with Bill Clinton and so on.

What is going on here, she actually did the exercises. The cosmonauts, in fact, were undisciplined and did not do theirs. These do work if they are implemented in a rigorous fashion. However, I still prefer having the artificial part of it so you don't have to do that. But, anyway, this thing flies out to Mars, it takes 6 months to get to Mars, which is within our existing space experience, and you land it at Mars at site No. 1, where there are fully fueled Earth return vehicles waiting for you.

The other Earth return vehicle is your backup so that if you don't need it, you can land it at a new site, site No. 2 to prepare the next human mission, which would fly there 2 years later, along with another Earth return vehicle, which is there for backup, which otherwise opens up site No. 3. So the idea here is you can do this, launching two boosters every 2 years, one to open up a new site, one to be at the previous site.

Two boosters every 2 years is an average of one per year to support a continuous program of human exploration of Mars. If we can launch them at the same rate as we launch the shuttles, which we probably could because it's basically just a shuttle with another stage. You are talking about using maybe 16 percent of your existing heavy lift launch capability to support this kind of initiative.

This is an actual photograph of the Mars space plant. Here is your Earth return vehicle sitting on the ground. There is your reactor in the background. There is the upper deck habitation, lower deck is the garage and the pressurized ground rover that can tap off some of the fuel you made on Mars to travel around Mars with a vehicle powered by a conbustion engine. This is another important thing.

If you can make fuel on Mars, you cannot only use it to get home, you can use it to get around on Mars. A combustion engine powered vehicle is going to have a lot more mobility than one powered by batteries like a little golf cart or something and we are not going to Mars just to say we went there. We are going to Mars to explore a planet and if we have capability on the planet, we've got to be able to do things on the planet, particularly with mobility.

So to adopt this travel light and live off the land approach, it is not only the cheap way to go to Mars, it's the potent way. So now you are on Mars, you are going to be there a year and a half, because that is how long you have to be there until the launch window opens up to go back to Earth. You do lots of field exploration, dwarfing the sort of field exploration that could never be done by robotic vehicles.

At the end of that time, you get in the Earth return vehicle, you take off and you go home directly to Earth. You leave the HAB behind on Mars. So that after a string of these missions have occurred, you basically have a string of warming huts scattered across the Martian surface that basically are within long-distance driving range of each other.

You are opening up a broad area of Mars to human cognizance. We are not actually going to relocate Texas to Mars, this is just your district, if you are concerned about that. However, after a certain number of the missions have occurred—the initial missions you do want to spread out because you want to explore both for scientific reasons and for prospecting reasons, as it were. But after a certain period of time, the key questions that are going to relate to Mars is not going to be this question of was there ever life on Mars. However, that is a very important question, and it's a question of great and philosophical importance, but the real question about Mars is will there be life on Mars, because, you see, Mars, unlike the Moon, unlike certain of the Earth orbit, Mars is the place that has on it all the resources that are needed to support not just life, but some day a new branch of civilization.

It's got water, it's got carbon dioxide, it's got nitrogen, which are the elements of life, and it's got the elements of industry; sulfur, phosphorus, silicone, iron, plutonium, alluminum, copper. It's got all this stuff and if we can go to Mars and develop the craft on how to use these materials, we can turn them into resources because what is and is not a resource depends upon the craft you bring to the problem.

If we go there and we learn not just how to make fuel and oxygen on Mars, which is what we need to do to do our very first mission feed, but how to grow crops on Mars, how to extract water from the soil, how to make bricks, surroundings, glasses, plastics, metals, tubes, wires. If we develop that craft, by developing what is in your mind, you turn back an inhospitable environment to one that can sustain people, and we can plant the first branch—the first seeds of the new branch of human civilization on a new world, and, frankly, it's within our capability and it's a privilege.

A lot of people are interested in the Moon. I think the Moon is a goal with less order than Mars. However, if you do this right with the same hardware that you use to build a base on Mars, that can also be used to build a lunar base, and I really think that should be our approach. That is in the same way we created a space station in the afternoon by doing Apollo.

We created the *Saturn 5,* we can launch a space station like that. If we do Mars with this sort of approach, we can also establish lunar bases for astronomy or whatever purpose. So to be brief, this is the entire set of tools you actually need to establish the first human settlements on the Moon and Mars if you go at it in this way. You need a heavy lift booster with a good throw stage. We know how to develop that.

You do not need giant explanatory space ships, you do not need giant explanatory space ports, you do not need fusion power drives or any of this other stuff, just a good booster with a good throw stage. You can throw payload to either the Moon or Mars. And then you need two fundamental types of payloads, an HAB module that you can send to the Moon or Mars, although you have to insullate it differently, in a different temperature environment, and an Earth return vehicle to come back from either the Moon or Mars.

It is virtually the same vehicle, it has got two stages to come back from Mars, one stage to come back from the Moon and arrow shell modules used on the Moon. This is not a $450 billion program here. It does not remotely resemble any such thing.

When I first proposed this plan back in 1990, it was considered out in left field by NASA, who are committed to the older mode. However, by around 1992, the number of people there finally came around and they subjected this to an examination, and decided to go with it, but they decided to design their own version of the mission, scaled up by a factor of two compared to how I designed it, so I called their mission to Mars semi-direct.

But even so, it was the same basic approach, direct flow to Mars, use of Martian air starting on the very first mission. They costed it out, the same people, by the way, who costed out the report at $450 billion. They costed out their bloated Mars records at $50 billion. I think if you slip it down, you can cut that in half.

So we are talking about the Humans to Mars Program can really be done within a decade, not for hundreds of billions of dollars, but for tens of billions of dollars, which admittedly is not cheap. It is not pocket change, but it is a sum that this country can easily afford if we are talking about opening up a new planet to humanity and inspiring an entire generation to excellence and scientific education. So what needs to be done right now? Start phase A.

NASA programs are all phase A, B, C, D. A is the preliminary design, B is the detailed design to decide where the rivers go, C, you build it, D, you fly it. Phase A is usually less than 1 percent of the program cost, but takes up about 25 percent of the program time. We can, with negligible impact on the NASA budget, do the phase A of the Humans to Mars Program right now, and the idea is to have that report ready to throw on the desk of the President-elect in November 2000.

Why? To do the home work now so that NASA can say to the man elected or the woman elected in 2000, look, here is our plan. The whole agency is willing to sign off on this level of risk. These are our detailed cost estimates. These are our designs. We can have people on Mars by 2008, by the end of your second term, the choice is yours.

John F. Kennedy was willing to send people to the Moon or committed the Nation around it to send people to the Moon just on the feeling that we are Americans and we can do anything, OK. But today people like to see the numbers before they make the commitment. If we are going to have a commitment from the administration to launch something as large as the Humans to Mars Program, in my opinion it almost certainly has to come in the first year of their turn, when they have the most wind in their sails, and such a program would best be carried out by a single two-term administration, so you can have a degree in political continuity requiring it. Therefore, the ideal time to hit the beach is November 2000.

We have to commission NASA now to do the phase A, to throw on the desk of that person, and then you can have a break down of the space in the first decade of the 21st century. So I am going to conclude with a quote. OK. This is a quote I lifted from a book called "A Plymouth Plantation," written by William Bradford, the leader of the pilgrams.

He wrote this book in 1621, 1 year after the Mayflower landing. And what he is talking about here is the debate that erupted among the pilgrims when they were in Holland, and they didn't like the way things were going there, and they didn't know where people got them, and what some guy came up with was the totally bizarre suggestion that what they ought to do was relocate the entire population of the civilized Netherlands into the wilds of North America because however hard it might be, there they would be able to cut their own path, there they would be able to make their own world. And he says the following.

He says,

> This proposition, being made public and coming to the scanning of all, it raised many variable opinions amongst men and caused many fears and doubts amongst themselves. Some, from their reasons and hopes conceived labored the stir-up and duress to undertake and prosecute the same. Others, again, out of their fears, objected against it and sought to divert from it, alleging many things and those neither unreasonable nor unprobable and that it was a great design and subject to many unconceivable perils and dangers. It was answered that all great and honorable actions are accompanied with great difficulties and must be both enterprised and overcome with answerable courages.

I put that up there because, look, I have just shown you in a very brief way this Humans to Mars plan. If you want to see it in more detail, read my book, it's all there. But despite the fact it is by far the cheapest way anybody has ever proposed to get to Mars, I believe it is the safest because the relatively small vessels can be completely checked out on the ground, where you can check things out, as opposed to in orbit, and there is back-up and artificial gravity and all the rest of this.

But the fact of the matter is, it's got to be a commitment. In fact, if we commit to going to Mars, we are undertaking a lot of risk and it is going to be very risky to go to Mars the first time, and that is going to be true whether we do it my way in 2007 or we advocate and start with responsibility and leave it to a far future generation or some other nation to do it in 3007. But if you look at human history, and I don't care where you look, whether you look at 376 years ago or what people were doing 52 years ago, one thing is very clear, and that is that nothing great has ever been accomplished without courage. Thank you for your attention.

Mr. Weldon. Thank you very much, Dr. Zurbin.

I would like to next turn to Mr. Rogers.

Mr. ROGERS. Mr. Chairman, I appreciate being invited here this morning. We are speaking today about spending very large public sums. Therefore, I have a politically pragmatic 5-minute statement.

Half a dozen years ago, our civil space leaders envisioned a 10 percent per year program real growth through the decade of the nineties. Purchasing power actually made available has been steadily decreasing. This trend is expected to continue, resulting in a difference of $100 billion over a decade.

Why this extraordinary reduction in public support, in view of the clear, widespread and continuing public interest in space? Our Civil Space Program was created at a time of great apprehension about the technological capability of the Soviet Union. The extraordinarily successful Apollo Program helped ease our national security concerns. So, when civil space leaders then asked to be allowed to conduct a space exploration activity, a grateful American public quickly agreed. But that was a quarter of a century ago. And our general public has not seen enough produced by the program that is of great and continuing interest to it, relative to other publicly supported activities.

Our civil space leaders seemingly find it difficult to differentiate between a general public interest in space, which continues to be high, and a general public constituency for the space program, which continues to erode. That is our challenge, to differentiate. Therefore, in cooperation with our private sector, the ensemble of space activities conducted by the program should be refashioned to give it a greater emphasis on those things which many, many more of us personally, and which would be pleasing to us, and which have a much greater interest in and value to many, many more of us than today.

Here are three examples of such things in the human space flight area. One, you have already heard of this morning. Buzz Aldrin and I have recently noted that over 10 million of us visit space-related museums and installations throughout the country each year. This is a business already, a space tourism business of $1 billion a year. Poll after poll suggests that some 40 percent of our population wish to take a trip to space. Some 80 million people in the United States alone think of that in the context of the term "constituency." Such a new space business could grow to tens of billions of dollars a year, and if it came about, today's view of space would be fundamentally changed.

Second, aging-related life sciences research, in orbit, physiological difficulties observed in the human cardiovascular system, reduced lung capacity, loss of bone calcium, mimic what happens to all of us as we grow older. This reversible phenomenon can be thought of as accelerated aging. Large scale research studies, conducted under microgravity conditions, could be helpful in dealing with the diseases and disabilities of our large and rapidly growing elderly population.

Third, space sports. With the local influence of gravity on human movement in low Earth orbit, without it, wholly new sports could be created there and new sports records established. Communications business interests would see them launched throughout the world and widespread interest and excitement would be created in space that is dominated today by scientists and technologists. God help us, I am one.

But two problems must be dealt with in order for such kinds of economically and socially desirable changes to come about. First, we must understand that the unit cost of basic space infrastructure and activities remains enormous. They are 1,000 times to 100,000 times as great as at the surface.

Two, many civil space people are apprehensive about their personal futures, if a large part of today's Federal program is taken up by private business interests. Therefore, in this context, I would make three suggestions to you. First, our Federal Government has a vital role to play in reducing unit space costs. It decided to do so for transportation. Now, the highest priority of our multibillion-dollar per year Space Station Support Program should be that of bringing about privatization of the Space Stations operations. Thereby, laying a basis for commercialization.

Second, the Secretaries of Commerce, Energy, and Transportation should now be asked to take a greater interest in civil space matters.

Third, and last, today's negative reward structure for civil space workers must be changed, so as to encourage space commercialization efforts to succeed. Therefore, we should take a fundamentally new step forward. We should establish a human Moon, Mars exploration and settlement budget line item for NASA. We should do it now and then we should fund it in proportion to the business revenues generated in the human space flight area.

The new tax revenues generated thereby would pay for it, and both our space and public economic interests would benefit.

Mr. Chairman, I provided the staff with papers that deal with these observations and details.

[The prepared statement of Mr. Rogers follows:]

Mr. Chairman, thank you for inviting me here this morning.

Each month we learn of, and wonder about, new space feats of our civil space program's Shuttle fleet, science satellites, solar system probes and Hubble space telescope.

But, while a half dozen years ago our civil space leaders envisioned a 10% per year program real growth throughout the 1990s, the purchasing power actually made available has been steadily decreasing, a trend expected to continue -- resulting in a difference of $100 billion !

Why this extraordinary reduction in public support in view of the clear, widespread and continuing public interest in space ?

Our civil space program was created at a time of great apprehension about the technological capability of the Soviet Union. The extraordinarily successful Apollo program helped ease our national security concerns. So, when civil space leaders then asked to be allowed to conduct space exploration activities, a grateful American public quickly agreed.

But that was a quarter of a century ago, and our general public has not seen enough produced by the program that is of great and continuing interest to it relative to other publicly supported activities. Our civil space leaders seemingly find it difficult to differentiate between a general public interest in space, which continues to be high, from a general public constituency for the space program, which continues to erode.

Therefore, in cooperation with our private sector, the ensemble of space activities conducted by the program should be refashioned to give greater emphasis to those which involve many more of us personally, and which have a much greater interest and value to many more of us.

Here are three examples in the human space flight area:

1. Space Tourism

Over 10 million of us visit space-related museums and installations throughout the Country each year -- a business of some $1 billion. But poll after poll suggest that some 40% of our population wish to take a trip to space -- some 80 million people in the U.S. alone. Such a new space business could grow to $10s of billions per year. And today's view of space would be fundamentally changed.

2. Aging-Related Life Sciences Research

In orbit, physiological difficulties observed in the human cardiovascular system, reduced lung capacity, and loss of bone calcium, mimics what happens to all of us as we grow older. This (reversible) phenomenon can be thought of as "accelerated aging". Large scale research studies conducted under microgravity conditions could be helpful in dealing with the diseases and disabilitiies of our large and rapidly growing elderly population.

3. Space Sports

Without the local influence of gravity on human movement in Low-Earth-Orbit, wholly new sports could be created there and new records established. Communications business interests would see them watched throughout the world. And widespread interest and excitement would be created in space that is dominated today by scientists and technologists.

But two problems must be dealt with for such kinds of economically and socially desirable changes to come about:

1. The unit cost of basic space infrastructure and activities remains enormous -- they are 1,000X - 100,000X as great as at the surface.

2. Many civil space people are apprehensive about their personal futures if a large part of today's Federal program is taken up by private business interests.

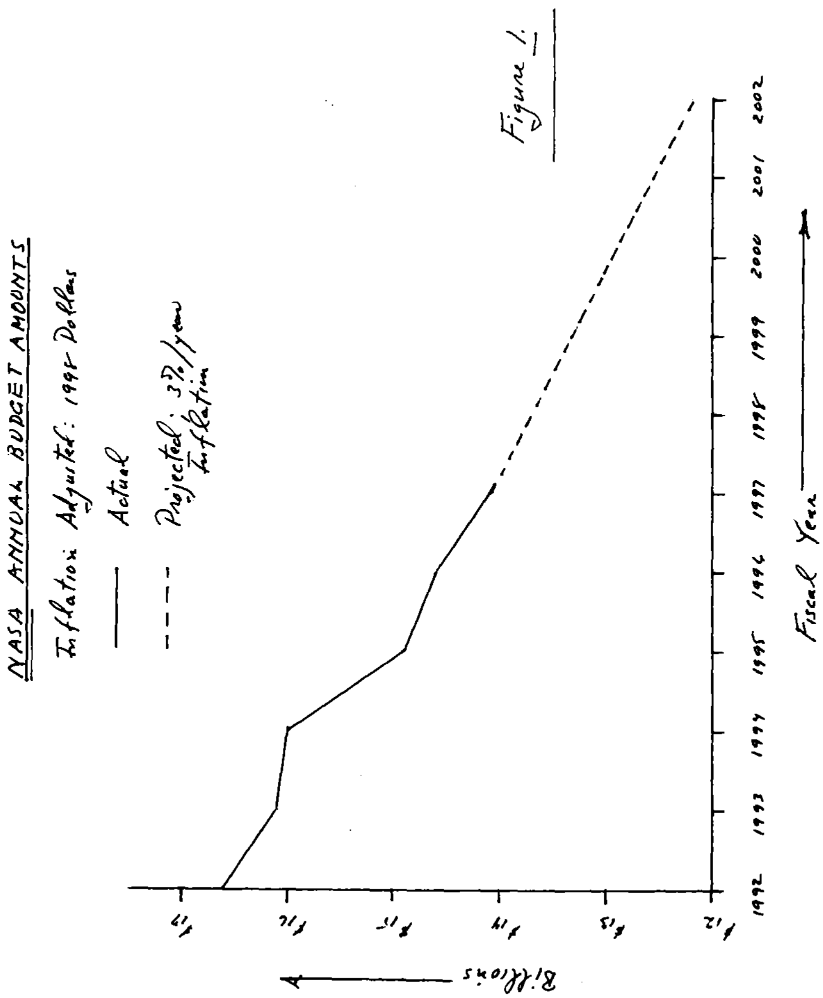
I would make 3 suggestions:

1. Our Federal government has a vital role to play in reducing unit space costs. It has started to do so for transportation. Now the highest priority of our $ multi-billion per year Space Station support program should be that of bringing about privatization of Station operations, thereby laying the basis for commercialization.

2. The Secretaries of Commerce, Energy and Transportation should be asked to take a greater interest in civil space matters.

3. Today's negative reward structure for civil space workers must be changed to encourage "space commercialization" efforts to succeed. We should take a fundamentally new step forward: we should establish a human Moon-Mars exploration and initial settlement program NASA budget line item and then see it funded in proportion to the business revenues generated in the human space flight area. The new tax revenues generated thereby would pay for it, and both space and public economic interests would benefit.

Mr. Chairman, I have provided your staff with papers that deal with these observations in detail.



NASA ANNUAL BUDGET AMOUNTS
Inflation Adjusted: 1998 Dollars
Actual
Projected: 3%/year Inflation
Figure 1.
$12
$13
$14
$15
$16
$17
Billions
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Fiscal Year

NIH ANNUAL BUDGET AMOUNTS

Inflation Adjusted: 1997 Dollars

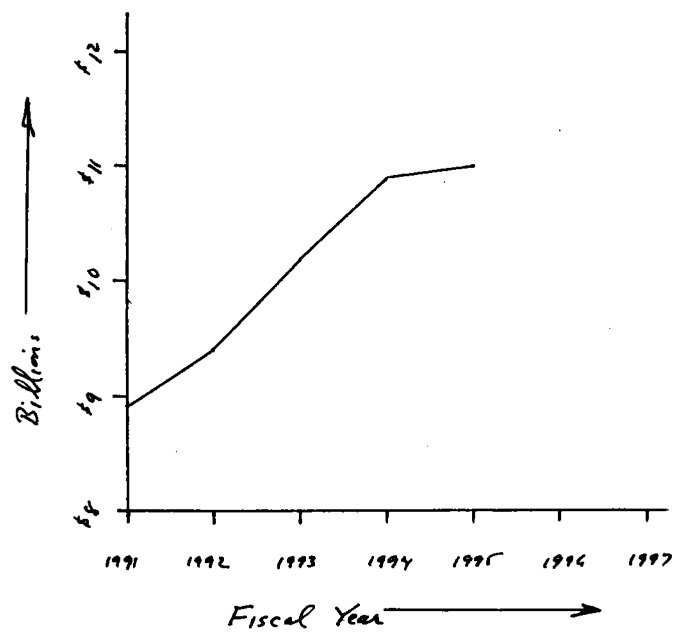


Figure 2.

See the two Figures, attached.

References.

- "Report of the Advisory Committee on the Future of the U. S. [Civil] Space Program"; December, 1990.
- "What The United States Must Do To Realize The Economic Promise Of Space", a report of the Aerospace Research and Development Policy Committee of The Institute of Electrical and Electronics Engineers Inc. (the IEEE); December 17, 1993.
- "Space Tourism: The Perspective from Japan and Some Implications for the United States", T. F. Rogers; The Journal of Practical Applications of Space; Winter, 1995; Vol. VI No. 2.
- "Large-Scale Commercial-Industrial Business In The Human Space Flight Area – Using the Space Station and its Support Program To Do So", T. F. Rogers; April 15, 1997. (Unpublished.)
- "Why And How To Obtain Public Approval For A Moon-Mars Human Exploration And Settlement Program – A New Way of Justifying Such a Program and Paying for It", T. Rogers; April 11, 1997. (Unpublished.)

Mr. WELDON. Thank you, Mr. Rogers.

Dr. Potter.

Mr. POTTER. Mr. Chairman, I want to start out by thanking you for inviting me to speak with you this morning. I feel that it is especially a privilege to address this committee because given its wide jurisdiction, you will be able to put what I say into relevant environmental, social and economic issues, not just technical issues. The specific issue I want to discuss is one of the more innovative energy technologies to be proposed during the oil crises of the 1970's. That is the solar power satellite.

I believe Peter Glaser, who first originated this idea in 1968, described it to you a week ago in the hearing. And as you recall, it was intensively studied by NASA and the Department of Energy during the 1970's. The result of the study was a reference, strawman solar power satellite concept, which would orbit the Earth at an altitude of 22,000 miles, the traditional geostationery orbit of communication satellites, so they would always stay over one spot on the Earth.

The problem was that given this—the way the energy is transmitted back to the Earth, that is low density radio waves at microwave frequency, the beam will spread out to several miles at the surface of the Earth. This is true whether you put one watt into the beam or billions, so you are going to have to put 5,000 megawatts of electricity into this beam in order to make economical use of the land that is going to be needed to soak up the energy.

At the Earth's surface, you have a large field of small antennas known as a rectifying antenna or rectenna, which converts the microwaves back to electricity. Now, two things happened, which kind of put a damper on this concept. No. 1 was the sheer size of it, coupled with the high cost of launch to space, which we thought was going to go way down from the 1970's levels and didn't.

The other issue was the relatively low cost of oil. When the oil crisis ended, space solar power did not look competitive. Nevertheless, the idea is receiving increasing attention in recent days due to concerns about the environmental effect of burning fossil fuels. We are still left with large size and hence the large first cost of the idea.

The idea itself, in my opinion, is very elegant. If you had a ring of solar power satellites in geostationary orbit and some amount of space infrastructure and space travel capability to maintain them and perhaps replace them, you can power civilization indefinitely with no cost in fuel, and what I believe to be minimal impact on the environment. However, it is hard enough to get a 5,000-megawatt power plant financed on Earth, let alone at an attitude of 22,000 miles. This is four to five times the size of the typical power plant, so if I may borrow a phrase Dr. Aldrin used earlier this morning, what we need to do figuratively and literally is bring the idea down to Earth.

We have studied this idea for a number of years at New York University and we have identified a few major issues as crucial to the development of space solar power, and I am going to briefly run through them. One I have already alluded to is the cost of access to space, since there are usable launch vehicles such as the X–33 currently being researched. It is hoped this will be less of an issue over the next few years than it is now.

Coupled with this, it is the development of new materials that did not exist during the study of the 1970's. You can lower the cost of launching a pound of mass to orbit. What you can also do is lower the mass of the thing you want to supply to power. In recent years, a number of companies have developed thin film solar cells, deposited on light weight flexible substrates. It is not just the theoretical possibility, it looks approximately like this. In fact, it looks exactly like this.

This is an actual production piece of a thin film solar cell made by a company in Ames, IA, and you can imagine something like this being fashioned into a light weight, possibly inflatable structure, and erecting itself into space.

Our next major issue I have also alluded to briefly is the environmental cost of fossil fuel burning implied by the U.N. Climate Convention. If, for example, the nations of the Earth decide that they want to tax carbon emissions, then the cost of power from space becomes somewhat more attractive compared to conventional power.

Our fourth major issue is the demographic facts of life in developing nations. According to the Intergovernmental Panel on Climate Change, by the year 2025, something like 95 percent of the population growth, and 75 percent of the expected carbon emissions growth will come from developing nations. Many of these people may be able to leapfrog directly over the era of conventional fossil fuel burning power plants, directly into space solar power.

Our fifth major issue is the relationship between space solar power and communications. A number of companies have proposed building large arrays of satellites in low to middle Earth orbit. We proposed that you may be able to combine the capabilities of power beaming and communications, over the same beam. The frequencies and the technologies are similar, you just need a lot more power. We were inspired by this rather lowly device, which is the telephone cord, which supplies both power and the voice signal to your phone.

For students under 30, I call it a computer modem cord, but the idea is the same. So to summarize my remarks, I believe that space solar power has the advantage over conventional renewables in that you get more power per unit land area and also has the advantage over other power sources in that it is pollution free and no new physics needs to be studied. The technology is right in front of us.

Mr. Chairman, I want to thank you again for inviting me and I would like to request that two papers for me and my colleague at New York University be entered into the record.

Mr. Weldon. Without objection, so ordered.

[The information referred to follows:]

APPLICATIONS OF THIN-FILM TECHNOLOGY IN SPACE POWER SYSTEMS

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Abstract

Solar power satellites (SPS's) have been proposed as a means by which energy from the sun can be collected continuously in geostationary orbit, and transmitted to rectifying antennas (rectennas) on the Earth. Recent advances in thin-film technology may allow for significant reductions in the amount of mass needed to supply a given amount of power. Lightweight flexible substrates can be coated with a thin film of photovoltaic material. Furthermore, if solid-state microwave transmitters can be deposited on the same substrate, then nearly the entire area of the substrate is available to serve as both solar collector and transmitting aperture. Because a larger transmitting aperture emits a less divergent beam, smaller SPS and rectenna areas become possible. If large numbers of thin-film SPS's are necessary, it may be possible to lower their cost even further by using lunar materials. The combination of a lunar infrastructure and thin-film technology may pave the way toward a lunar power system (LPS) which would involve solar collectors and microwave transmitters on the Moon, and microwave reflectors in low Earth orbit. Other future applications of this technology are solar sail space probes as well as demonstration SPS's in low Earth orbit.

Introduction

A major constraint on the deployment of solar power satellites (SPS) is the cost of launching construction material into space. Two research strategies have been pursued in order to alleviate this problem. One approach is to build the SPS out of non-terrestrial (particularly lunar) material. This approach has been supported for many years by the Space Studies Institute (SSI) in Princeton, NJ. Launching a given amount of material from the Moon to high Earth orbit takes less than a twentieth as much energy as launching the same amount of material from the Earth[1]. When other factors, such as atmospheric resistance on the on the Earth, are accounted for, the savings in launch costs from the Moon versus the Earth may amount to a factor of fifty. In 1985, Space Research Associates completed an SSI-commissioned study[2], in which NASA/US Department of Energy reference SPS design[3] was redesigned to take full advantage of lunar resources. It was shown that approximately 99% of an SPS can consist of lunar materials. The 8% increase in overall mass compared to an SPS built from terrestrial materials was considered to be a relatively small price to pay for this advantage.

The SPS designs mentioned above have masses of about 50,000 metric tons and generate 5000 megawatts of electricity. Recently, therefore, another strategy for reducing SPS launch costs has been considered. Work at the NASA Lewis Research Center has shown that thin-film solar cells can be deposited on a lightweight substrate; furthermore, the addition of solid-state microwave transmitters integrated onto the same substrate may eventually be possible[4]. If the entire area of the substrate can be covered with microwave transmitters as well as solar cells, large effective transmitting antenna diameters become feasible. Due to the physics of power beaming, the larger the transmitting antenna, the less the microwave power beam will spread as it reaches the Earth. Because the rectifying antenna (rectenna) at the Earth's surface can now be made correspondingly smaller, the SPS need not supply as much power as a conventional SPS in order to be economical. With smaller SPS's having a lower mass per kilowatt of power generated, the system becomes easier to build and finance.

Recent research at New York University, supported by SSI, aims to achieve the best of both approaches to launch cost reduction by using thin film photovoltaics and lightweight substrates built from terrestrial or lunar materials[5,6]. The first step in the study was to consider two lightweight SPS designs suggested by Geoffrey Landis and Ronald Cull of the NASA Lewis Research Center: the "bicycle wheel" and the "inflatable sphere"[4]. The bicycle wheel SPS would consist of a disk-shaped solar cell/transmitter array stretched out over spokes, with a pole running through its center. The primary goal of the SSI/NYU study was to design a lightweight SPS which makes use of thin-film photovoltaic materials and solid state microwave transmitters deposited on lightweight substrates. Throughout the study, "traditional" requirements on SPS's were adhered to whenever possible (e.g., geostationary orbit, microwave power transmission, etc.), but were altered if necessary to facilitate the design of a simple, easily launched SPS (e.g., new materials; integrated, rather than gimbaled, antennas; etc.). The study is a "first order" design. Future designers may need to alter such things as frequency (depending on federal and international frequency allocations) and total mass (depending on an eventual selection of type of thrusters, as well as a more detailed consideration of the structural design). Electromagnetic thrust (pushing against the Earth's magnetic field) should be investigated as a means of keeping the mass low. Power for this can be siphoned from the solar array.

Power Transmission

An important consideration in SPS design is the need to transmit power from geostationary orbit to the Earth. The NASA/US Department of Energy reference design utilized microwaves at a frequency of 2.45 GHz. This is a well-understood frequency, with equipment such as magnetron tubes readily available. Since the physics of power transmission causes the beam to spread out into a 10 x 13 km area on Earth (for a 1 km transmitting antenna), the reference SPS had to transmit large amounts of power (5 gigawatts) in order to be economical. One of the advantages of a thin-film SPS is that if solid state microwave transmitters and solar cells can be integrated onto the same substrate, then larger transmitting antenna arrays are possible. If each transmitter element is powered only by the solar cells in its immediate vicinity, then losses along power buses from the solar cells to the antenna are minimized. Furthermore, the design is simple, consisting of the same element repeated many times, as well as durable (since few single parts are critical to the overall operation of the SPS). For the study, the entire surface of the SPS is assumed to contain both solar cells and integrated transmitters. Thus, as the SPS diameter is increased, more power is squeezed into a tighter microwave beam. The SPS was sized so that the peak beam intensity at the Earth's surface is 30 mW/cm^2. This figure is the same as that used in the previous SSI-sponsored study on SPS's built of lunar materials[2], and is similar to that from the NASA/US DOE study (i.e., 23 mW/cm^2). It has been suggested that higher values, such as 40 to 50 mW/cm^2 may be acceptable[7]. Thus, a value of 30 mW/cm^2 is in keeping with previously accepted intensities, while still allowing for some leeway in the design.

Frequencies higher than 2.45 GHz lead to smaller, more feasible SPS's. However, frequencies higher than about 10 or 15 GHz are subject to attenuation in rain as well as clear air (although there are "windows" in clear air at 35 and 94 GHz)[8,9,10]. In addition, the efficiency of solid state microwave transmitters decreases with frequency. Therefore, 10 GHz was chosen as the baseline frequency for the study, although this should be considered provisional, as regulatory issues were not considered.

The nominal latitude for the study is 35°, in keeping with the NASA/US DOE reference design. The intensity of the power beam is dependent on the latitude, although it is not highly sensitive to it (at least, for latitudes below about 60°). Thirty-five degrees is not far removed from most of the world's population centers, so the resulting design will be practical for many regions. If the same design is mass-produced to power many areas, the peak intensity at higher latitudes will be less than 30 mW/cm^2, while the peak at the equator will be just under 40 mW/cm^2. Alternatively, the design can be customized for each latitude. In the calculations for this study, the SPS-to-rectenna distance and the beam angle from vertical at the Earth's surface were corrected for latitude. Distances were thus somewhat greater than the geostationary altitude of 35,786 km. Beam angles from the vertical were slightly greater than the latitude.

The energy distribution of a microwave beam consists of a central main lobe, where most of the energy is concentrated, as well as sidelobes. Sidelobes can be minimized by the proper choice of beam taper (i.e., a variation in the intensity of the beam across the face of the transmitting antenna), although the main lobe then becomes broader. Beam tapering involves redistributing the power across the face of the integrated SPS, which complicates the design, and may lead to power distribution losses in the SPS. Although these losses may not be large, a more dilute beam will require a larger SPS in order to maintain economically high beam intensities. In order to design the smallest economical SPS, the study emphasized untapered microwave beams.

Consider a uniformly illuminated circular phased array transmitting antenna. If the individual antenna elements are spaced no more than one-half wavelength apart, then the beam intensity at the rectenna site is:

$$I(u) = I_o \left\{ \frac{2\, J_1(u)}{u} \right\}^2 \qquad (1)$$

where $J_1(u)$ is the first order Bessel function of the first kind.

The variables used here are defined as follows:

I_o = peak intensity of untapered beam at rectenna = $\frac{\pi P_t}{4} \left\{ \frac{D_t}{\lambda h} \right\}^2$

λ = wavelength

h = altitude

P_t = transmitted power
D_t = transmitting antenna array diameter
u = non-dimensionalized distance from center of beam pattern at rectenna = $r\left\{\frac{\pi D_t}{\lambda h}\right\}$
r = dimensionalized distance from center of beam pattern at rectenna.

This equation applies to a beam that is perpendicular to the ground. The beam from a satellite orbiting over the equator transmitting power to a latitude of ϕ_o will have an angle of ϕ from the vertical, where:

$$\phi = \phi_o + \arcsin\left[\frac{R_e}{h}\sin\phi_o\right] \qquad (2)$$

and R_e is the radius of the Earth. (The angles are expressed in radians.) Note that if $\phi \neq 0$, the altitude h (measured from the rectenna) is slightly greater than the altitude h_o of the satellite as measured from the equator. If h_o is the altitude of the satellite as measured from the equator, then

$$h = \sqrt{h_o^2 + 2(1-\cos\phi_o)\,R_e\,(R_e+h_o)} \qquad (3)$$

The value of h computed in Equation 3 is used in the calculations of I_o and ϕ in Equations 1 and 2. For rectennas at high altitudes and low latitudes, h and ϕ will differ little from h_o and ϕ_o, although the differences were accounted for. For a latitude of 35° and an altitude of 35,786 km (geostationary orbit), the values of ϕ and h were 40.6° and 37,119 km, respectively. The peak intensity can now be corrected for beam angle, since the deviation of the beam from vertical will cause the peak intensity to decrease by a factor of cos ϕ as the power is spread out over a larger area. The corrected intensity, I_c, is thus:

$$I_c = I_o\cos\phi = \frac{\pi P_t}{4}\left\{\frac{D_t}{\lambda h}\right\}^2\cos\phi \qquad (4)$$

The transmitted power (P_t) can be computed by recalling that for the thin-film SPS, the entire surface area may be covered with solar cells and solid state microwave transmitters. Thus, the solar collector diameter and area are the same as those of the transmitter array and are D_t and $\pi D_t^2/4$, respectively. Thus, the transmitted power is given by:

$$P_t = \frac{S_o\,\pi\,D_t^2\,\eta}{4} \qquad (5)$$

where S_o is the solar constant (1373 W/m^2) and η is the overall efficiency at which the SPS converts sunlight into microwave energy. The parameter η can be found by multiplying the efficiencies of the first nine system elements in Table 1.

If the expression for P_t in the right side of Equation 5 is substituted into Equation 4 and the resulting equation solved for D_t, then the following is obtained:

$$D_t = 2\left\{\frac{I_c}{S_o\,\eta\,\cos\phi}\right\}^{1/4}\sqrt{\frac{\lambda\ h}{\pi}} \qquad (6)$$

If c is the velocity of light and f is the frequency of the transmitted beam, then $\lambda = c/f$. Substituting this into Equation 6 gives:

$$D_t = 2\left\{\frac{I_c}{S_o\,\eta\,\cos\phi}\right\}^{1/4}\sqrt{\frac{c\ h}{f\ \pi}} \qquad (7)$$

where h and ϕ are given in Equations 3 and 2, respectively. Thus, for a given SPS altitude, rectenna latitude, and power beam frequency, the allowable peak beam intensity determines the diameter of the smallest feasible SPS. Larger SPS's are possible if the power transmission beam is spread out wider than the diffraction limit. This can be achieved through beam tapering. SPS's that are significantly smaller than that given by Equation 7 are not feasible, because a lower-powered, more spread-out beam will result. Thus, the rectennas will have to be larger, and may not even be able to collect power in much of the outer area of the main lobe, if the beam intensity is insufficient to activate the rectenna diodes.

Choice of Materials

Researchers[4,11] have investigated several different thin-film photovoltaic materials. Amorphous silicon (a-Si) compares favorably with other materials, such as CdS, Cu_2S, and $CuInSe_2$ in terms of efficiency. All of these materials are radiation-tolerant, thereby eliminating the need for a protective cover glass. They are also low in mass, and therefore, inexpensive for the quantities that will be needed. Amorphous silicon is at a slight disadvantage in terms of light degradation (10 to 15% after two years, compared to, say, $CuInSe_2$, which has none[11]), but it is believed that this can be improved upon. Because of its favorable characteristics, and the fact that it is the only thin-film photovoltaic material available on the Moon, amorphous silicon served as the basis for this study. If SPS designers wish to substitute a different material for the SPS built of terrestrial materials, the results of this study are still applicable, since the efficiencies are similar. Ref. 4 reports that a-Si cells with an efficiency of 9.0% were available as of 1988, and projected an efficiency of 11.5% for the 1990's. The latter figure was used in this study (although these efficiencies were actually for a-Si on a thick substrate). A degradation of 4% due to radiation is given in Ref. 12 (page 164). The materials considered for the substrate are Kapton polyimide for an SPS built of terrestrial materials (25μm thick in the near-term; 7μm thick in the long term) and steel foil for an SPS built of lunar materials (25μm thick in the near-term; 7.5μm thick in the long term)[13]. The long-term thicknesses were used in this study. For array mass calculations (cells plus substrate), specific powers (watts per kilogram) given in the literature[4,13] were based on cell efficiencies of 5, 10, or 15%, so they were rescaled for an efficiency of 11.5%. The area densities of advanced cells (substrate, photovoltaic material, and metallization) are 15.8 g/m^2 for terrestrial materials and 59.8 g/m^2 for lunar materials.

Support structures for a bicycle wheel-type SPS should consist of lightweight materials, in order to take advantage of the mass savings available from thin-film solar cells and substrates. Suggested materials are silicon carbide (SiC), for an SPS built of terrestrial materials) and glasses such as basalt fiber, glass ceramic, and fiberglass, for an SPS built of lunar materials)[14,15].

SPS Design Tradeoffs

Two different SPS designs were considered, based on Reference 4: bicycle wheel and inflatable sphere. The inflatable sphere has the advantage of needing no support structure, other than a low-pressure gas to inflate it. In addition, it always has an entire hemisphere facing both the sun and the Earth. However, its effective area for both the solar cells and the transmitting antenna array is equal to its cross-sectional area, not its total surface area. Thus, the array is four times more massive than if it were a flat disk. Power from the sun-facing part of the array must be redistributed to the Earth-facing part. The power must be redistributed still further, since the limb of the Earth-facing side will have more transmitting elements per cross-sectional area than will the center, due to the fact that the limb is seen edge on. This may not greatly increase the mass or complicate the design; in fact, the power redistribution network can be deposited on the interior of the sphere[16]. The curvature of the array causes a transmitter phase difference across the Earth-facing side, which can be compensated for. In addition, the inflatable sphere has more surface area from which to radiate heat.

The bicycle wheel SPS is shown schematically in Figures 1 and 2. Such an SPS can be designed so that it can transmit from either the same side that collects the energy or from the opposite side. It will have to switch from "two-sided" to "one-sided" use and back again each day, probably at dawn and dusk (see Fig. 2). During at least one of those times, the SPS will briefly be edge-on to either the Earth or the sun, thus interrupting the power. Some storage capability at the ground may therefore be necessary. When designing a bicycle wheel-type SPS, an allowance must be made for the tracking loss, because the array cannot simultaneously point at both the sun and the Earth, except at midnight and at noon. A tracking loss of 30% was assumed, based on Landis and Cull's (Ref. 4) figure for an SPS in orbit around the Moon. It is possible that this can be improved upon. The worst-case situation occurs at dawn and dusk, at which times the sun and Earth are 90° apart. Phased-array antennas can steer a beam up to 60° from either side of the normal to the array surface. Thus, the normal to the array need not deviate from more than 30° from a line to the sun. Because the cosine of 30° is 0.866, the loss in solar energy collected need never be more than 13.4%. Since the beam is being slewed up to 60°, and the cosine of 60° is 0.5, the effective transmitter array diameter (as seen from the Earth) is halved along one axis. There will therefore be some additional loss due to the fact that the beam spreads out more, possibly overspilling the rectenna. The rectenna width can be doubled along one axis, thereby doubling its area and capturing the otherwise lost power. However, there may be a more serious loss caused by the fact that the intensity of the beam will be halved (in addition to the loss in intensity caused by the fact that the collector surface no longer faces the sun squarely). Thus, the outer parts of the beam may fall below the intensity needed to activate the rectenna diodes. It may be possible to minimize this loss with advanced rectenna designs. Calculations were also done for a bicycle wheel SPS with no tracking loss. This can be achieved if the array points toward the Earth and a mirror orbiting with the array reflects sunlight toward it. Such a mirror might consist of aluminum on Kapton[17], plus an appropriate support structure and might weigh more than the SPS itself; the increase in system mass is thus 2.1 times that of a system with a tracking loss (in which the size or number of SPS's is increased to compensate for the lost power). (The factor of 2.1 is explained below.) Such an increase in mass may be deemed worthwhile if the fluctuation of the power level of a non-tracking array as it orbits the Earth turns out to be a serious problem.

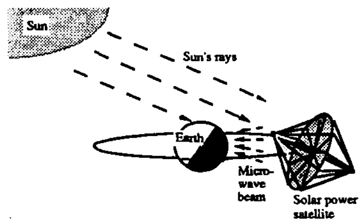

Fig. 1. "Bicycle wheel" thin-film solar power satellite. Solar energy is collected and beamed to Earth in the form of microwaves. (Adapted from Reference 4).

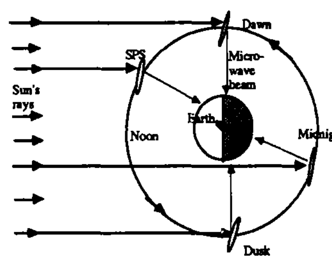

Fig. 2. Two-sided "bicycle wheel" thin-film solar power satellite as it orbits the Earth during the course of a day. Viewpoint is "above" the North Pole. Note that the SPS makes a transition from "two-sided" use (that is, collecting solar energy on one side and transmitting it from the other) to "one-sided" use and back again each day. For an "inflatable sphere" SPS, this transition is continuous.

System Efficiencies

The microwave power level incident on the rectenna is considerably different from the power level of sunlight incident on the SPS. Furthermore, the power available to consumers is somewhat less than that incident on the rectenna. In addition to the inefficiency of the solar cells and tracking losses, other inefficiencies must be accounted for. The efficiencies used in this study are based on Table 1 from Vondrak (Ref. 7), but with modifications. They are shown here in Table 1. Note that atmospheric transparency had to be adjusted for latitude (because an oblique beam cuts through more atmosphere than a beam at the equator) and for frequency. It is significant mainly at higher frequencies, such as 35 GHz and 94 GHz.

Table 1: Solar Power Satellite System Efficiencies

System Element	Efficiency	Reference
1. Satellite attitude control	91%	Ref. 7
2. Solar cell efficiency	11.5%	Refs. 4, 11
3. Radiation degradation	96%	Ref. 12
4. Array effective area efficiency	95.1%	Ref. 7
5. Array/ antenna power distribution	99%	Estimate (Potter)
6. DC to RF conversion	55% (frequencies ≤ 10 GHz) 40% (35 GHz) 30% (94 GHz)	Based on Refs. 16, 17
7. Trans-mitting antenna	96.5%	Ref. 7
8. Atmo-spheric transparency (examples)	98.9% (10 GHz to equator) 98.6% (10 GHz to 35° latitude) 93.5% (35 GHz to 35° latitude) 77.0% (94 GHz to 35° latitude)	Based on Refs. 8, 9, 10
9. Tracking efficiency	70% (Bicycle wheel) 100% (Bicycle wheel with mirror or inflatable sphere)	Ref. 4
10. Rectenna energy collection	83.8%	Refs. 9, 18
11. Rectenna energy conversion	88%	Ref. 7
12. Interface to utility grid	97%	Ref. 7

SPS Size and Power Level

When the first nine efficiencies in Table 1 are multiplied together and the result substituted for η in Equation 7, the size of an SPS whose peak beam intensity (I_c) is 30 mW/cm^2 at the Earth's surface can be computed. For a bicycle wheel SPS (without a mirror) beaming power to a latitude of 35° at a frequency of 10 GHz, the diameter is 2020 meters and the power incident on the Earth's surface (Equation 5) is 153 megawatts. When the last three efficiencies in Table 1 are accounted for, it is seen that 109 megawatts is available to consumers. The rectenna energy collection efficiency is based on the percent of the power of an untapered beam that falls within the main lobe[9,18]. The mass of the solar cell/transmitter array is 51 metric tonnes. This does not include the mass of the support structure. Initial estimates for support structure masses were quite low - approximately 1.6 tonnes[6]. A value of about 10 tonnes has also been suggested[19], and will be used in this report. Since this is about 20% of the mass of the array, the net area density will, in effect, increase from 15.8 g/m^2 to 1.20 times this, or 19.0 g/m^2. This net area density will be used to obtain mass estimates for other bicycle wheel designs as well. Furthermore, since the bicycle wheel SPS built from lunar materials is subject to similar stresses, the same 10-tonne support structure may suffice for a 2020-meter-diameter SPS. (Of course, these support structure masses are rough estimates, and should be considered provisional.) This yields a net area density of 63.0 g/m^2. Results were also obtained for a bicycle wheel design with a mirror, an inflatable sphere, as well as SPS's with other frequencies and latitudes. The masses of the inflatable sphere design were obtained by considering a flat array with no tracking loss and multiplying the mass by 4 (since the surface area of a sphere is 4 times its cross-sectional area); however, the area density used was not corrected for the presence of a support structure. Furthermore, the mass of the inflation gas was not considered, since it is negligible compared to that of the array (even when considering the extra gas needed to compensate for leakage)[6]. For the bicycle wheel with mirror, the mirror will need to be sized to compensate for the maximum tracking loss. This occurs at dawn and dusk, when the Earth and the sun will be 90° apart from the point of view of the SPS. If the SPS faces the Earth squarely at those times, it will be edge-on to the sun. A mirror at a 45° angle to the SPS will therefore be needed. In order for the mirror to have the same effective area as the SPS, it must be elongated by a factor of $1/\cos 45° = \sqrt{2} \approx 1.414$ along one axis, compared to the SPS. Its area will, of course, increase by the same factor. However, it may be more practical to maintain the circular shape, especially if the mirror is spin-stabilized. Thus, the diameter will increase by $\sqrt{2}$ along the entire plane of the mirror. The area will thus increase by a factor of 2 over that of the SPS. For the purpose of a rough estimate, the mirror will be assumed to have the same net area density as the SPS. Thus, the system mass will be three times that of the SPS itself. Since the 30% tracking loss will be eliminated, it will have 1/0.7 or 43% more power, so that its power per unit mass is 1.43/3 or 48% that of a bicycle wheel without the mirror. This is a system mass increase factor of $3/(1/0.7) = 2.1$ per unit power delivered. If the mirror is elongated by $\sqrt{2}$ along one axis only, the power per unit mass will be $1/[(1 + \sqrt{2})\cdot 0.7]$ or 59% that of a bicycle wheel without the mirror. A peak beam intensity of 30 mW/cm^2 at the Earth's surface was assumed in all cases.

The results of the size and mass calculations are summarized in Table 2. The types of SPS referred to in Table 2 are bicycle wheel (b.w.), bicycle wheel with mirror (b.w.m.), and inflatable sphere (i.s.). The first three rows of the table can be thought of as reference designs, with the rest of the table included for comparison. Note that rows 9 through 11 show that the design is only mildly sensitive to latitude (at least, for latitudes in which an SPS is practical). Rows 4, 1, 7, and 8 show that the design is highly sensitive to power beam frequency.

The specific power levels (power per unit mass) were computed by dividing the power delivered to consumers by the total masses (including a mirror where appropriate) built from terrestrial materials. (Specific power for lunar materials is much higher, but is less of an issue.) Results indicate that frequencies of 10 GHz and below have the highest specific power, due to the higher microwave transmitter efficiencies and lesser atmospheric absorption than at higher frequencies. The bicycle wheel without the mirror has the highest specific power of the three designs considered.

The last two rows in Table 2 show that for a bicycle wheel in equatorial low Earth orbit (here, 1200 km), masses on the order of 0.5 to 1.7 tonnes are possible. (Lunar masses are shown for comparison, but may not be applicable to low Earth orbit SPS's.) These SPS's (or at least, the materials for their construction) can be lofted in one launch with existing vehicles. The power levels shown are not continuous, but are only for times when the satellite "sees" both the sun and the rectenna. Continuous power during the day can be provided through a combination of energy storage at the rectenna site and the deployment of many such SPS's and rectenna sites to maximize the power transmission duty cycle. However, even a single such SPS, or a small number of them, would be an effective demonstration project.

Table 2: Summary of SPS Sizes and Power Levels

Type of SPS[a]	Frequency of power beam (GHz)	Rectenna Latitude	Diameter (m)	Power at Earth's surface (MW)	Power delivered to consumers (MW)	System mass (metric tonnes) (terrestrial materials)	System mass (metric tonnes) (lunar materials)	Specific power (kW/kg) to consumers (terrestrial SPS)
1. b.w.	10	35°	2020	153	109	61	202	1.8
2. b.w.m.	10	35°	1850	182	130	153	507	0.85[b]
3. i.s.	10	35°	1850	182	130	170	643	0.76
4. b.w.	2.45	35°	4080	624	446	248	824	1.8
5. b.w.m.	2.45	35°	3730	746	533	623	2070	0.86[b]
6. i.s.	2.45	35°	3730	746	533	692	2620	0.77
7. b.w.	35	35°	1190	36	26	21	70	1.2
8. b.w.	94	35°	816	10.6	7.6	10	33	0.76
9. b.w.	10	0°	1850	128	92	51	169	1.8
10. b.w.	10	50°	2240	186	133	75	248	1.8
11. b.w.	10	60°	2490	229	164	93	308	1.8
12. b.w. (LEO)	10	0°	339	4.3	3.1	1.7	5.7	1.8
13. b.w. (LEO)	35	0°	183	1.21	0.86	0.50	1.7	1.7

NOTES: [a] b.w. = bicycle wheel; b.w.m. = bicycle wheel with mirror; i.s. = inflatable sphere; LEO = Low Earth Orbit (1200 km equatorial); unless "LEO" designation is used, all orbits are geostationary.
[b] b.w.m. masses are based on a circular mirror with twice the area of the SPS. If the mirror is elongated over one axis only, specific power is approximately 1.1 kW/kg. Masses of b.w.m. would thus be 20% less than shown.

Thermal Analysis

To find the temperature of a low mass SPS, the worst-case situation will be considered, namely, that the SPS squarely faces sun. (For the inflatable sphere, this is always the case.) The contribution from the Earth will be neglected for the reasons that follow. In near-Earth space, the intensity of sunlight is, as stated earlier, S_o = 1373 W/m^2. This amount is incident over the cross-section of both the Earth and the SPS. The Earth's albedo (reflectivity) is roughly 30% (Ref. 20, page 118). Since the Earth reflects sunlight over one hemisphere, which has twice the area of the cross-section, the flux of reflected sunlight over the day hemisphere is 0.30 x 1373 W/m^2 / 2 = 206 W/m^2. The remaining 70% of the sunlight incident on the Earth will be absorbed and re-emitted as infrared over the entire surface area of the Earth. Since the surface area of the Earth is 4 times its cross-sectional area, then the flux of infrared radiation from the Earth is 0.70 x 1373 W/m^2 /4 = 240 W/m^2. Thus, the total flux of electromagnetic radiation from the Earth is 206 W/m^2 + 240 W/m^2 = 446 W/m^2. However, the SPS is in geostationary orbit, 35,786 km over the Equator, and the Earth's equatorial diameter is 6378 km; thus, the SPS is 42,164 km from the Earth's center. The intensity of radiation from the Earth must be rescaled by the ratio of the area of an Earth-sized sphere (equivalent radius 6371 km) to that of a geostationary-orbit-sized sphere. Thus, the intensity of radiation from the Earth incident on the SPS is

$$446 \text{ W/m}^2 \times \left\{ \frac{6371 \text{ km}}{42{,}164 \text{ km}} \right\}^2 = 10 \text{ W/m}^2$$

which is negligible compared to the energy from the sun. In addition, about 54% of this energy is infrared, the peak of which occurs at about 11 μm. Since the band-gap of silicon is 1.1 μm[21], a coating for the SPS could be designed to reflect the deep infrared from the Earth (and, more importantly, the sun), while still absorbing sunlight of wavelengths less than or equal to the band-gap.

To find the temperature of the bicycle wheel or inflatable sphere SPS, it will be assumed that the entire structure is at a uniform temperature. This is reasonable, because it is so thin. For an SPS of uniform temperature in equilibrium with its environment,

energy absorbed = energy emitted, so by the Stefan-Boltzmann Law,

$$\alpha S_o A_c = \epsilon \sigma T^4 A_t \tag{8a}$$

Rearranging this gives

$$T = \left\{ \frac{\alpha S_o}{\epsilon \sigma} \left(\frac{A_c}{A_t} \right) \right\}^{1/4} \tag{8b}$$

where

S_o = solar constant = 1373 W/m² (effectively 1304 W/m² due to microwave beam)

T = temperature of SPS

A_c = cross-sectional area of SPS = area available for absorption

A_t = total area of SPS = area available for emission

α = solar absorptivity of SPS

ϵ = infrared emissivity of SPS

σ = Stefan-Boltzmann constant = 5.669×10^{-8} W/(m²K⁴).

The bicycle wheel SPS will absorb sunlight over one face, and emit infrared over both faces; thus, its ratio $A_c/A_t = 1/2$. The inflatable sphere will absorb sunlight over an effective cross-sectional area equal to π times the square of its radius. It will emit infrared over its entire surface area of 4π times the square of its radius, so $A_c/A_t = 1/4$. About 5% of the incident solar radiation is, in effect, emitted by the array in the form of the microwave beam (based on multiplying the first seven efficiencies in Table 1, using a DC to RF conversion efficiency of 55%). This is the reason for the reduced value of the effective solar constant.

Measurements of α and ϵ for amorphous silicon on Kapton have not been made, so approximations based on the component materials will be used (values are from Ref. 22). A silicon solar cell 1 mm thick has a solar absorptivity of 0.938, while that of 3 mils (75 μm) of glass on a silicon solar cell is 0.925. Thus, a figure of 0.93 will be used for amorphous silicon on Kapton polyimide. The two materials just referred to have infrared emissivities of 0.316 and 0.843. Dupont reports a figure of 0.7 for 0.3 mil (7.5 μm) of uncoated Kapton. This figure will be used for amorphous silicon on Kapton, because it is similar to that of the average of two types of silicon solar cell, and it is unlikely that the combination of materials will differ significantly from the substrate or the coating. Putting these figures into Equation 8b results in a temperature for a bicycle wheel SPS of 352 K (78°C). The temperature for the inflatable sphere SPS is 296 K (22°C).

The solar absorptivity and infrared emissivity of aluminum foil coated with 10 μm of silicon will serve as an approximation to the SPS made from lunar materials, since figures for amorphous silicon on steel foil were not available. These numbers are 0.522 and 0.12, respectively. Substituting the appropriate constants into Equation 8b gives 473 K (200°C) for the bicycle wheel SPS and 398 K (125°C) for the inflatable sphere.

The inflatable sphere has an advantage over the bicycle wheel in terms of the temperature for SPS's made of either terrestrial or lunar materials. Terrestrial materials yield better (i.e., cooler) temperatures than lunar materials. The temperatures for the latter are high enough to affect the efficiency of the solar cells, so developing high-infrared-emissivity coatings may be worthwhile, even if there is some mass penalty. However, it must be noted that these conclusions are tentative, due to the approximate nature of the thermal properties used. More definitive results must await experimental measurements on the thermal properties of thin-film solar cells.

<u>Comparison of Old and New Reference Designs</u>

The 10 GHz designs from Table 2 can be viewed as new reference designs and compared to the NASA/US DOE reference designs. Ref. 3 discusses two such designs: one using crystalline silicon solar cells; the other using gallium aluminum arsenide solar cells. Their masses are 51,000 tonnes and 34,100 tonnes, respectively. Both consist of a 5 x 10 km rectangular solar array with a 1 km circular antenna array. Both provide 5000 MW of power. This gives a specific power of 0.098 kW/kg for the Si version and 0.15 kW/kg for the GaAlAs version. Comparing this with Table 2 shows that the thin-film SPS represents an improvement in power delivered per unit mass of 5 to 18 times. Even if the bicycle wheel version (without the mirror) were to double in mass (due, say, to the addition of thrusters, or a more massive support structure), it will still be six times lighter (per unit power delivered) than the lighter of the two NASA/US

DOE reference designs. Furthermore, this still leaves enough leeway for the addition of a reflecting mirror. As seen in Table 2, the bicycle wheel with mirror and the inflatable sphere each require more mass per unit power delivered than the bicycle wheel without the mirror. This may be an acceptable price to pay for a more steady supply of power. However, while the bicycle wheel with mirror compares favorably with the inflatable sphere in terms of mass, the complexity and, possibly, the fuel required to keep the mirror co-orbiting with the solar array may render it unfeasible. It may be subject to an additional loss due to the difficulty in keeping the mirror optically flat. Designs using lunar materials are substantially heavier than those using terrestrial materials, but still represent an improvement over conventional SPS's. The decision of whether to use terrestrial or lunar materials will depend on global energy requirements, launch costs, and the cost of building and operating a lunar infrastructure.

Advanced Applications

Solar Power Statite

A limitation of geostationary communication satellites is their infeasibility for use at higher latitudes. Their "descendants," solar power satellites, will suffer from the same problem. A commonly-used method for circumventing this limitation is the use of inclined orbits, such as Molniya orbits. Several satellites are necessary for continuous coverage, and they must be tracked by the ground stations. Recently, another method for transmitting signals to high latitudes has been proposed by Forward[23]. A spacecraft based on solar sail technology could be held aloft "above" a high latitude by balancing solar radiation pressure against the Earth's gravity. Such a spacecraft is referred to as a "statite" in Ref. 23. It would not be in orbit, but in static equilibrium at a distance of 30-250 Earth radii from the center of the Earth at 45° to 60° latitude. It will actually be stationary with respect to the Earth-sun system, not the Earth itself, which will rotate "beneath" it. It will thus appear to rotate around the polar axis once a day. It is a straightforward matter to track it, because it would be visible continuously. Due to its great distance, the radio delay time will make it feasible only for broadcasts or data, not for real-time conversations.

The statite concept is appropriate for supplying power as well. The transmission delay time is not relevant for a "solar power statite." Forward has shown that equilibrium statite positions exist for sails with area densities of up to 10 g/m^2, and perhaps more. The bicycle wheel SPS may have an area density of 19 g/m^2, so it is possible that it could be held aloft by solar radiation pressure if it is far enough from the Earth. If necessary, the average area density could be decreased by attaching some thinner (non-photovoltaic) reflective sail material to the outer edge of the SPS. This may also be necessary to give the SPS some reflectivity, so that the net solar radiation force is directed in the opposite direction from the Earth's gravity.

Lunar Power System

The Lunar Power System (LPS)[24] is related to the SPS, but would beam power from solar collectors on the Moon to the Earth. Microwave reflectors in Earth orbit would be needed to supply power to the side of the Earth from which the Moon is not visible. Thin-film technology may be used for either the lunar component or the Earth-orbiting component. The lunar component would be inexpensive to manufacture, since it would consist of large rolls of material, rather than panels. (This may even be a precursor to more advanced applications, such as easily deployable solar cells for a Mars base.) If the microwave reflectors can be made thin enough, then some of them could be operated as statites.

Light Sail Probes

Solar (or light) sail propulsion has been under consideration for many years. Near-term designs could be propelled by the pressure from sunlight. In the long term, lasers might be used to supply the thrust. Usually, highly reflective sails are considered, since they would have greater thrust than absorptive materials. However, Potter and Matloff[25] have shown that the bicycle wheel SPS can be operated as a photovoltaic light sail. Although the thrust is not as high as a reflective light sail, the photovoltaic cells could be used to supply power for microwave communication from great distances to small receiving antennas on the Earth. The power available can even be used to operate an ion thruster. The microwave beam can be steered electronically, allowing for some degree of steering of the sail. If microwave receivers can be integrated into the sail, it can function as a radio telescope.

Conclusions

The results shown above indicate that the reference designs for a thin-film SPS should be based on a power beaming frequency of approximately 10 GHz. Lower frequencies may be desirable if larger SPS's are required. Higher frequencies may make possible a "mini-SPS," which can serve as a demonstration project, or be used to supply power to small, remote villages in areas with little rainfall. The precise frequency to be used will depend upon regulatory requirements. A bicycle wheel design without a mirror may be the simplest in the short run, and it has the highest specific power of the three designs considered. However, its variation in delivered power during the course of its orbit may make it more difficult to integrate into existing power grids. Adding a reflecting mirror would alleviate this problem, but at a cost of extra mass and the added complexity of co-orbiting the two structures. Thus, the inflatable sphere SPS may be more feasible in the long run, because it is mechanically simple, has no cosine tracking loss, and dissipates heat better.

A major issue in the deployment of thin-film SPS's is the use of lunar versus terrestrial materials. It is likely that terrestrial designs will prove useful in the short run, allowing thin-film SPS's to be deployed before a lunar infrastructure is built. In addition, approximate analysis shows that thermal properties for terrestrial materials are better. Due to the large number of SPS's that may eventually be needed, combined with the need to replace aging SPS's, a lunar infrastructure may eventually become necessary. This decision may also depend on whether or not a transition to a lunar power system is planned.

In addition to the lunar power system, other applications of thin-film technology include solar power statites and light sail space probes.

To date, thin-film solar cells have been produced at manufacturing volumes far below that required for SPS construction. The substrates commonly used are thicker than those discussed here. Furthermore, there has been little or no research in integrating solid state microwave transmitters onto the same substrate as thin-film solar cells. However, the promise of thin-film technology, combined with future world energy needs, suggests that it is worthwhile to develop manufacturing technologies which would allow thin-film solar cells and solid state microwave transmitters to be deposited on lightweight substrates and produced in large quantities.

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ENERGY AND INFORMATION FROM ORBIT: TECHNOLOGIES FOR THE GREENHOUSE CENTURY

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Where there is no vision, the people perish. - Proverbs 29:18

INTRODUCTION

One of the most ingenious global scale energy technologies studied during the Energy Crisis of the 1970s was the solar power satellite (SPS). As conceived in 1968 by Czech-American engineer Peter Glaser, the SPS would collect solar energy from photovoltaic arrays some 50 square kilometers in area deployed in geostationary orbit (GEO), and beam power to the Earth's surface by microwaves for distribution by conventional electric utility grids (Glaser, 1968; Koomanoff and Bloomquist, 1993).

Important as this pioneering concept was, it is now clear that power from space can be achieved by technologies as diverse as those of, say, heavier-than-air flying machines; technologies that differ from each other in detail as much as the Concorde differs from the Wright Flyer. But just as any aircraft design must obey the principles of aerodynamics, space power systems too are constrained by physical laws. Figure 1 shows some of the physics of electromagnetic wave propagation that bear on space power. Figure 2 illustrates three generic system concepts proposed thus far employing space-based components to provide electric power on Earth; and Table 1 summarizes parameters specific to the DoE/NASA Reference Design of 1970s based on the original Glaser proposal.

A fundamental advantage of SPS is that solar collectors in sufficiently high orbits are exposed to roughly ten times the long-term average solar flux per unit area as those on the surface. Accordingly, any system that can deploy and maintain orbiting collectors and transmit their energy to ground stations at less than ten times the cost of ground-based solar cells has the potential to be cost-effective relative to terrestrial solar electricity. Also, because of the high efficiency of microwave transmission to the surface, the microwave antenna ground stations can deliver more electricity per unit land area than surface renewables (Strickland, 1996) -- an important factor in land-limited developing nations. The devil is in the details. For reasons discussed below, funding for SPS by government R & D agencies evaporated in the US in the late 1970s. And only recently has the Space Power option begun to be reexamined by NASA (SAIC, 1995).

TABLE 1. SPS Reference Design of the DoE/NASA program of the 1970s (Koomanoff and Bloomquist, 1993).

Total number of SPS	60
Single SPS power [GW]	5
Solar cell panel size [km]	5 x 10
Transmitting antenna diameter [km]	1
Single SPS mass [10^6 kg]	30 - 50
Specific power [kW/kg]	0.1 - 0.2
Ground receiving system size at 35 degrees latitude [km]	10 x 13
Density of power radiation in the center of transmitting antenna [kW m^{-2}]	30
Density of microwave power in the center of the ground receiving system [W m^{-2}]	230
Capital investment for 20 year development period including the first SPS launch [$ billion]	110 - 120*
Cost of each following SPS [$ billion]	11 - 12
SPS operation time [years]	30
Period of SPS economic return [years]	6

* Or $25 billion without cost of the development and construction of special launch systems.

The Geostationary SPS concept was (and is) elegant; a ring of such Solar Power Satellites in equatorial orbit could power human civilization indefinitely. But even if the engineering feasibility of a GEO SPS could be established credibly it difficult to imagine the financial environment that would permit such systems to be built in the coming decades. This is partly a consequence of the physics underlying the geostationary Glaser concept: The 36,000 kilometer orbital altitude; the 12 centimeter microwave wavelength (corresponding to the 2.45 GHz frequency where there is an atmospheric window and well-understood technologies to generate the microwave beam); and the physics of electromagnetic wave diffraction. Collectively, these mandate a very large transmitter antenna in space and large rectennae on the ground to maintain reasonable power transmission -- roughly, one and ten kilometers in diameter, respectively, for the Reference Design of the 1970s. The orbiting solar collector array in GEO must also be huge to provide cost-effective areal power densities in the beam, although the Cost of Electricity (COE) might be reasonable -- always assuming that space transportation costs from the Earth or from the Moon are reasonable.

But regardless of the COE in cents per kilowatt-hour produced by the system, a project of this magnitude simply boggles the mind. Too much is at risk to hazard it as a first step. This was understood by Peter Glaser himself, who argued for a terraced approach, leading over time to the geostationary SPS. An even more practical system would be profitable in the early stages as well as later (see below). But this was not explored. Once the Energy Crisis of the 1970s was over, funding for SPS evaporated -- apparently under the assumption that if the Reference Design was unfeasible then it was unreasonable to support any research on Space Power. The decision to drop support for Space Power in general turned the field into a cottage industry for the few "keepers of the flame".

Still, the emergence of innovative technologies and products in the marketplace can be triggered in unexpected ways by evolving commercial infrastructures -- consider, for example, the explosive emergence of the World Wide Web once the Internet established its ubiquity.

We argue here that a similar windfall for SPS could open up by exploitation of constellations of global communications satellites currently being planned. Strategically targeted research now by NASA and DoE could lead to second generation SPS systems that could be economically viable in the near term by integrating the space power and communication functions. Environmental bonuses of this technology are reduced global warming from fossil fuel burning, reduced biodiversity loss from excessive land use characterizing most terrestrial renewable energy sources, and more sustainable economies in general in the developing nations of the tropics.

CARBON-FREE POWER FOR THE GREENHOUSE CENTURY

On considering the slim menu of greenhouse-free energy sources capable of powering a global 21st century economy, our Earth Systems Group at New York University has focused on solar power satellite (SPS) systems beyond those pioneered by Peter Glaser -- a class of technologies largely neglected by funding agencies since the DoE/NASA Study of the 1970s Energy Crisis. At this point our research priorities are technology and systems studies leading to greenhouse-free SPS technology demonstrators oriented toward Third World energy demands, possibly incorporating integrated solar collector and microwave antenna elements on thin film substrates.

Our studies identified the following issues as major: (1) synergies with constellations of communications satellites, (2) access to space costs as a fraction of the levelized cost of electricity (COE), (3) development of low-mass inflatable satellites, (4) environmental costs of fossil fuel burning implied by the UN Climate Convention and (5) the demographic facts of life in developing nations. All of these can, in our view, drive the development of Space Solar Power-- perhaps by free market entrepreneurs. A bibliography of relevant NYU publications is given at the end of the text along with a list of other sources cited here.

Most of the energy demand (and carbon emissions) in the next century will come from developing nations. Mid-range projections by the Intergovernmental Panel on Climate Change (IPCC) based on United Nations data show 95% of population growth and 75% of carbon emissions growth by the year 2025 coming from developing countries (Leggett et al., 1992). By the middle of the next century the human population will be 10 billion of which less than 15% -- some 1.4 billion people -- will live in presently developed countries and 8.7 billion will live in developing countries. Apart from growing energy demand, the developing nations, which are primarily in the tropics, will experience inexorable pressure on their land resources to feed their growing populations -- precisely the reason environmentalists fear tropical deforestation and biodiversity loss in the Third World.

Ground-based renewable energy systems like terrestrial photovoltaics and biomass fuels provide relatively low areal energy density -- typically less than 10 watts electrical per square meter (continuous). This could significantly divert land use from agriculture and natural ecosystems, and hence contribute to global environmental degradation. Orbitally-energized SPS microwave rectennae should be able to provide 100 watts electrical perimeter continuously, even accounting for reasonable microwave power safety margins at the rectenna perimeter (Strickland, 1996). Whether a factor of ten reduction in land use requirements compared with (say) terrestrial PV cells can be achieved is a researchable issue, and could be critical for the viability of space power.

It is important to factor in the cost of transmission and storage of inherently intermittent renewables in computing the cost of electricity (COE) -- costs which are often ignored in analysis of small-scale renewable electricity on grounds that existing power grids provide "storage". Neglecting transmission and storage costs of ground-based renewables is clearly inappropriate when the prime power supply is intermittent. Considering all of these factors, electric power from orbit from a constellation of satellites in LEO looks rather attractive. But remarkably, Space Power seems to have dropped off the table in discussions of mitigating the environmental effects of fossil fuel burning.

THE REEMERGENCE OF SPS

It is illuminating to compare near-zero funding for SPS over the past fifteen years with the forty years of continuous funding for controlled thermonuclear fusion stimulated by lobbying by the plasma physics and weapons communities. Without a power-generating fusion reactor in sight, the Clinton administration in 1995 requested $350 million for magnetic fusion research this year in the DoE budget. (The House of Representatives cut this to $220 million -- still, $220 million more than SPS.) The equivalent of tens of billions of present-day US dollars have already been spent worldwide on the fusion power enterprise.

Without minimizing the difficulty of fusion engineering -- reactions quenched by anomalous plasma diffusion, destruction of containment walls by neutron bombardment, magnetic field stresses, etc. -- we cannot help wondering what progress might have been made toward a global-scale nonfossil fuel energy source had even a fraction of this investment been made in Space Power. Interestingly, controlled thermonuclear fusion, the only competitor to SPS on the horizon as a long-term baseline electricity provider for human civilization, also has problems of first cost -- with current estimates projecting very large and expensive Tokamak power reactors (Furth, 1990).

One of the ironies of fusion versus SPS funding is that wireless power transmission (WPT) is so easily demonstrated compared with fusion. This was illustrated by a "pocket WPT" demo at recent conference in Kobe, Japan. The demo was simple light emitting diode (LED) wired across a small diode, with the leads of the diode sticking out as a dipole. The LED lit when held near the door latch of a microwave oven. The point was not to demonstrate any great technical feat, but as a simple reminder that to demonstrate fusion one needs a Tokamak, but to demonstrate WPT, a tiny pair of diodes and a common appliance are enough.

Some thermonuclear neutrons have been produced in laboratory plasmas from fusion reactions at great expense by magnetic confinement. But plasma instabilities have thus far prevented confinement for long enough to extract usable energy at a practical level. And recent estimates of plasma turbulence suggest that the proposed $10 billion International Experimental Reactor (ITER) designed to show that fusion can be a practical energy source is problematical (Glantz, 1996). The truth is that outside of hydrogen bombs detonated by uranium or plutonium nuclear fission explosions the liberation of fusion energy for practical purposes remains a distant prospect.

We are not arguing against continued fusion research. Humankind in the next century will require every carbon-free energy source that can be mustered. Rather we wonder how future historians will reckon the costs of not developing Space Power when it might have been technologically feasible to do so. There is always a cost when one gives up too early or when a potentially promising idea is not explored for lack of a champion. That Space Power is not yet on the official menu of 21st Century energy options has already lead to some misguided analysis.

For example, when the National Academy of Sciences recently considered the mitigation of global greenhouse warming they didn't include Space Power as an option at all; although they did consider certain advanced technology approaches based on planetary-scale "geoengineering" (NAS, 1992). One geoengineering scheme was Space Mirrors deployed at the first Lagrangian point (L1) of the Earth-Sun system. The Mirrors would block incident sunlight and thereby compensate for global warming by CO_2 emissions.

Indeed, the NAS panel estimated Space Mirror costs in their "low cost" range (less than $9 per tonne CO_2 emissions avoided). However, the cost-pacer of virtually all space systems is access to orbit, a situation NASA is working hard to improve. Whereas the NAS considered a range of nonfossil energy alternatives -- nuclear, hydroelectric, geothermal, solar photovoltaic, solar thermal, wind and biomass -- they did not examine greenhouse-free Solar Power Satellites, which may have comparable masses and space transportation costs to Space Mirrors -- but unlike Space Mirrors, Space Power produces economically valuable electricity in addition to displacing CO_2 emissions. Were the value of power produced by SPS charged against their cost, the result would likely be a cheaper solution than cooling a fossil-fueled Earth with Space Mirrors. In principle, the net costs in $ per tonne of CO_2 displaced could be near zero or even negative.

A study organized by John Mankins of NASA's Office of Space Access and Technology presently underway (SAIC, 1995) is the first reexamination of Space Power by a US government agency since the National Academy of Science report fifteen years ago (NAS, 1981). This is appropriate, as access to space is a major cost-pacer. We would hope that the mitigation of global warming and the importance of economic growth of developing nations -- both of which are recognized by the US in the Rio Climate Convention -- will be factored into the analysis.

Despite the funding desert in the US for SPS research since the 1970s, work has continued elsewhere. In contrast to much US thinking that the Climate Convention will restrain economic development, the Japanese tend to treat it as a business opportunity. For example, Japan's Ministry of Technology and Industry (MITI) "New Earth 21" program views Space Solar Power as "an essential part in the proper control of CO_2 levels and in sustainable management of Earth's environment" -- carbon-free electricity being a commodity that can be profitably marketed worldwide. The SPS 2000 "straw man" designed by Japan's Institute of Space and Astronautical Science (ISAS) and supported by MITI is a kite-like orbiter 1100 kilometers above the equator with gravity-gradient stabilized transmitting antennae on the Earthward face, and solar collectors on spaceward triangular faces (Figure 3). SPS 2000 was specifically designed to demonstrate microwave power beaming of orbitally-collected solar energy to receiving stations in the tropics -- the latitude zone of developing nations.

Despite the best efforts of energy conservationists and advocates of terrestrial renewable energy (Johansson et al., 1993), there is a growing consensus that as yet unidentified carbon-free energy sources will be needed in poor, mainly tropical, countries. Jose Goldemberg, former Minister of the Environment of Brazil and strong advocate of renewable energy in the developing world, recently concluded that "the simplistic idea that energy conservation and the enhanced use of renewables could solve the world's sustainability and environmental problems, particularly those of the developing countries, by the year 2020 is entirely unrealistic. All source of energy will be needed... The alternative for developing countries would be to remain at a dismally low level of development which, ironically, would generate additional, serious political problems and an unchecked population growth that would aggravate the problems of sustainability" (Goldemberg, 1985).

There may be no "magic bullet" to solve this problem. But we believe that constellations of solar power satellites in low earth orbit incorporating low-mass thin film technology could play an important role. We are exploring a scenario in which the US computer and communication industries already committed to high bandwidth multimedia communication satellites is stimulated by NASA research to evolve a new electric-power-from-space industry fostering sustainable development. This need not involve NASA second-guessing the marketplace. Rather, the system would emerge as a free market fallout of government research in the way that commercial jet airliners, computer chips and the Internet did.

SECOND-GENERATION SPS TECHNOLOGIES

One of the more interesting insights to emerge from the new science of complexity is that biological and technological systems often evolve by employing building blocks of pre-existing systems in innovative ways. An example cited by John Holland of the Santa Fe Institute is the internal combustion engine, composed of parts used in earlier technologies recombined in a way that led to a whole new transportation system. Similarly, the infrastructure of a twenty-first century space power industry could emerge from global communication components -- satellite constellations, microwave transmitters and receivers, ground stations and control systems -- reconfigured to provide the power transmission function. Such hybrid systems might be the most cost-effective way to test and exploit the technologies of a nascent space power industry.

The most recent review of SPS technology prior to the present NASA study was the Summer 1992 Study by the International Space University in Kitakyushu, Japan (ISU, 1992). Among other things, Stewart Nozette of the Strategic Defense Initiative Organization (SDIO) made a presentation to this study arguing that a constellation of satellites in LEO employing technology and architectures developed in the SDI program could provide Space Power at relatively low entry costs. Since development costs have already been borne by the SDI program, the collapse of the Former Soviet Union provides an opportunity to reap a high technology "peace dividend" for Space Power - if the technology works as advertised; and if it can be adapted appropriately.

Although Space Power as an SDI spin-off didn't fly (literally or figuratively), Nozette later became project scientist on the Clementine Mission, which obtained the first close-up images of the Moon since Apollo using a spacecraft employing miniaturized sensors developed by SDI. Although Clementine was primarily a Department of Defense project, not a NASA one, it may have been the first mission simpatico with the mantra of NASA Administrator Dan Goldin: "faster, smaller, cheaper, better." A pleasant surprise revealed by Clementine radar data is the strong indication of hitherto undiscovered water ice near the Moon's south pole (Nozette et al., 1996). If this lunar ice discovery stands up, it can have major implications for future utilization of lunar resources, with application to both SPS and Lunar Power Systems (Criswell and Waldron, 1991).

Nozette's SPS design examples featured a distributed power satellite constellation at 1200 kilometer altitude, whose circular orbits inclined 50 to 90 degrees to the equatorial plane would provide global coverage. The satellites were large, deployable, inflatable/rigidizable spheres or cylinders, lightweight but large in surface area -- a Macys Thanksgivings Day parade of floats. Solar energy is collected by thin-film amorphous silicon bonded to the surface of these balloon-like orbiting structures. Two means of transmitting energy to the surface were considered: (1) Near-infrared lasers beaming to photovoltaic cell receivers and (2) microwave phased-array transmitters beaming to rectennas. These are second generation SPS system concepts incorporating several technological innovations since the DoE/NASA Reference Design of the 1970s.

For example, our NYU group previously proposed ground-to-space microwave power beaming to energize satellite constellations. Among other things, we studied the sensitivity of ground-based powerbeam accessibility to orbital altitude and number of satellites. A similar issue arises in transmitting Space Power to the ground (with transmitter and receiver reversed) because electrical energy requirements tend to be continuous.

Another important concept is the inflatable, thin-film solar power satellite with surfaces covered by integrated solar cell-microwave transmitter elements, originally proposed by Geoffrey Landis and Ronald Cull of NASA Lewis Research Center (Landis and Cull, 1991). Subsequent analyses have been conducted at NYU of spacecraft made from thin-film materials deposited on lightweight flexible substrates. The next step is to fabricate such a material and test it, perhaps first as a balloon in the atmosphere and eventually in space.

Balloons in space are an old story. Echo I was a balloon employed as an early communication satellite to bounce radio waves back to Earth. Inflatables may also be adaptable in some version as power relay satellites. An interesting variations on the inflatable theme is the Power Bubble of Marshall Savage, an orbiting mylar balloon with one hemisphere transparent and one coated with an aluminum layer. Light entering the balloon through the transparent hemisphere reflects off the metalized hemisphere and converges in an area along the focal axis. The concentrated sunlight can be used to produce electricity by a steam turbine (Savage, 1994).

The feasibility of inflatable structures in space for antennae, sunshades and solar arrays is under study by NASA; albeit not yet in an overtly SPS context. Still, an important experimental milestone was the deployment by Space Shuttle Endeavour astronauts on Monday, May 20, 1996 of the Spartan

Inflatable Antenna Experiment (IAE) -- a 14 meter diameter antenna inflated by a nitrogen gas canister in orbit (Figure 4). The antenna was developed by L'Garde Inc., of Tustin, CA, a small aerospace business, in collaboration with the NASA Jet Propulsion Laboratory (JPL), of Pasadena.

The deployment dynamics and flight of the L'Garde/JPL Inflatable Antenna Experiment provided spectacular video clips for viewers of TV news, and subsequently, for Web Surfers. But such experiments also have important implications for thin-film inflatable SPS constellations of the type we envision. It is not such a very large step from the Shuttle Endeavour IAE tests to Space Power satellites assembled in orbit from inflated segments. In the Endeavour test, an optical system surveyed the antenna and measured the accuracy of the inflated surface at a variety of internal pressures and thermal conditions, thereby providing data for phased-array antenna and surface-bonded PV cell applications. All research involves risk. But were NASA to prioritize inflatable space structure research, the knowledge base to make cost-effective low-mass power satellites could evolve rapidly. Given the history of the last forty years, this is at least as good bet as controlled fusion. And the payoff to the economy and global environment could be huge.

THE COMSAT CONNECTION

Commercial Space Power will become a reality only if it can attract venture capital and succeed a business. This will require an infrastructure of space operations conducive to this technology. Such an infrastructure is currently under development by entrepreneurs planning to deliver vast amounts of information worldwide using satellite constellations in LEO. We are presently exploring the possibility of developing such an infrastructure by combining high bandwidth telecommunication satellites with microwave power beaming.

We have, for example, computed that an inflatable thin film SPS 150 meters in diameter in a 200 kilometer orbit exposed to the solar constant (1360 watts/meter squared) could produce an areal power density of roughly 100 watts electrical per meter squared on the ground by transmitting a diffraction-limited microwave power beam at 2.5 GHz using the satellite surface as an aperture. A similar system designed for 35 GHz could produce the same 100 W/meter-squared with an approximately 50 meter diameter satellite, although the total power collected would be correspondingly less. Continuous power output at 100 W/meter-squared level for transmission to a grid, or as a power supply to remote villages in the tropics, will require satellites transmitting energy space-to-space from light to dark parts of low earth orbit; and powerbeams locking onto surface rectennae as they overfly ground stations. However, very similar networking and transmission problems exist for satellite communications constellations; so there is a strong motivation to uevelop a unified approach.

The electromagnetic wave equations of Maxwell imply the possibility of broadcasting (or narrowcasting) both energy and information. It is well known that Nikola Tesla pioneered the present system of alternating current (ac) electric power transmission lines, prevailing only after a bitter commercial battle with his opponent Thomas Edison who favored direct current (Cheney, 1983). But Tesla's dream was wireless power transmission. He conducted experiments in Colorado Springs (and elsewhere later) near the turn of the century to explore this goal. As the technology of radio and TV evolved it became clear that broadcasting radio waves is a bad idea for power transmission (because the energy dissipates as it radiates from omnidirectional antennae) but a good idea for information transmission (because power level is less important than ability to carry information by modulating the amplitude or frequency of a carrier wave). But these conclusions only apply to the radio wave band of the spectrum. The ability to create electromagnetic radiation at microwave and higher frequencies opens up new possibilities: Firstly, more data can be transmitted per unit time (more bandwidth); and at the same time the beam can be focused electronically, as in a phased array radar beam.

High bandwidth telecommunication channels are routinely employed in cellular telephone networks. Current plans for satellite-based wireless communication include microwave transmission frequencies of 30-40 and 2.5 GHz -- the same spectral bands currently under consideration for space power beaming (Zysman, 1995).

Rather than interfere with each other, space power and communications functions could be performed synergistically. Microwave power beaming was demonstrated as early as 1975 by experiments at the Venus site of the Jet Propulsion Laboratory Goldstone facility where 30 kW of direct current power was obtained 1.6 kilometers from a parabolic dish transmitting at 2.45 GHz with an efficiency of 84% by a rectifying antenna (rectenna) invented by William Brown. Projecting power and/or data along a microwave beam line-of-sight is well within the state of the art although microwaves do not penetrate very deeply into the Earth. To transmit over significant distances on the Earth's curved surface one must ascend to orbit.

Fifty years ago Arthur C. Clarke saw the potential of geostationary orbit for global communication (Clarke, 1945). He considered the idea, but did not apply for a patent because the pre-Sputnik world was technologically unready to put anything into LEO, let alone GEO. Twenty years later, Early Bird, the first commercial geostationary communications satellite, was launched. And since then Comsats exploiting the fixed relationship of satellites and ground stations to link up the Global Village have become ubiquitous features of late twentieth century life. Indeed, communication satellites are the example usually cited of successful commercial ventures in space. However, if one can field enough satellites it becomes advantageous to use LEO, since beam spreading by diffraction is less and power more efficiently focused.

At this point in time -- and for reasons similar to those leading us to advocate LEO constellations for Space Power -- plans have been made by entrepreneurs to deploy constellations of communications satellites on a vastly expanded scale in the near future (Foley, 1995; Ropelewski, 1996). TABLE 2 summarizes the status of large LEO systems proposed by U.S. corporations alone.

TABLE 2. Status of large Low Earth Orbit communication satellite systems by U.S. corporations as of November 1996 (Ropelewski, 1996).

Satellite System	No. of Sats. (altitude)	Orbit Characteristics	Estimated Cost	Licensing Status
Motorola (Iridium)	66 (780 km)	6 orbital planes inclined 86.4° (11 satellites/plane)	$3.8 billion	granted
TRW (Odyssey)	12 (10, 344 km)	3 orbital planes inclined 50° (4 satellites/plane)	$1.8 billion	granted
Loral/ QUALCOMM (Globstar)	48 (1,414 km)	8 evenly spaced orbital planes inclined 52° (6 satellites/plane)	$1.5 billion	granted
Const. Comm. (Aries/ECCO)	46 (2,000 km)	7 orbital planes inclined 62° (6 satellites/plane)	$1.7 billion	pending
Mobil Comm. (Ellipso)	16 (520-7,846 km, 8,068 km equator)	2 elliptic planes inclined 116.6° (5 satellites/plane); 1 equatorial plane (6 satellites)	$564 million	pending
Teledesic	840 (700 km)	21 orbital planes inclined 98.2° (40 satellites/plane)	$9 billion	pending

Clearly, the perceived value of the bits per second flowing though LEO communications satellites to global markets is high enough to make these systems attractive to investors today -- even with presently high satellite launch costs.

As presently conceived, information will be relayed by these satellites digitally encoded as analog modulations of microwave carrier waves (Gagliardi, 1991), although there are competing modulation schemes designed to optimize scarce spectral bandwidth (Ropelewski, 1996). It is also widely recognized that the electromagnetic spectrum allocated to these applications is itself an economic bonanza, for which there is intense competition, and which may have to be purchased in the future. Still, the large-scale expansion of global satellite communications systems is seen by Wall Street as a plausible investment, particular when it is assumed that economies of scale will drive access to space costs down.

The energy to put a given mass into LEO is surprisingly low: some 10 kilowatt-hours per kilogram of payload. This is about the same as the energy per unit payload to fly across the US by commercial airliner, although the present cost of space flight is a thousand times higher. Two reasons that spaceflight is so expensive is the army of engineers and scientists required for a successful launch and the fact that much of the launch vehicle and/or tankage is thrown away each flight. Aware of this issue, NASA has studied ways to reduce launch costs by at least a factor of ten from the present $22,000 /kg of the Space Shuttle (NASA, 1994).

The result was a NASA-sponsored competition among aerospace contractors for a next generation Single-Stage-to-Orbit (SSTO) vehicle with the potential for airline-like operation. The winner was Lockheed Martin Skunk Works, legendary innovators in aircraft design from the U-2 to the Stealth Fighter (Rich and Janos, 1994), who plan to first build and test the $1 billion wedge-shaped reusable X-33 -- a one half size, one eighth mass, version of an eventual SSTO Space Shuttle replacement dubbed Venture Star. Figure 5 shows an artist's conception of Venture Star deploying a satellite from its payload bay, and compares the NASA X-33, the SSTO Shuttle replacement with the present Shuttle. The goal costs of $2,200/kg for Venture Star are oriented toward the global satellite communications systems; but they also have the potential to make Space Power cost effective, particularly in integrated power/communications satellites.

On the satellite side, The Teledesic Corporation of Kirkland, Washington, created by Craig McCaw (Mobile Telecommunications Technologies) and Bill Gates (Microsoft) plan to spend $9 billion to deploy a 840 satellites in 700 kilometer high orbits beginning in the year 2001 to deliver telephone, video and computer data to the entire world (Stix, 1994). The Teledesic system, illustrated in Figure 6, is the most ambitious of many such proposals that have emerged (TABLE 2). Regarding Teledesic, Nobel laureate Arno Penzias, former chief scientist at Bell Labs, has observed: "Nothing here violates the technology boundaries as we know them. They're not asking for mental telepathy or antigravity. Launching a low-orbit satellite has certainly been done for generations, and the idea of mass manufacture applied to this kind of technology seems perfectly straightforward" (Kupfer and Davis, 1996).

If it happens, Teledesic will even dwarf Iridium -- a massive system of 66 communications satellites in LEO providing voice, fax, data transfer and paging to the most remote spots on Earth -- to be deployed by Motorola and at a cost of $3.8 billion. (Iridium was named for chemical element number 77 because it was originally designed to have 77 satellites; the system was later changed to its present configuration, but the appellation "Iridium" survives.) Motorola has come under fire because it will employ frequencies in the range 1.616 - 1.626 GHz for its downlinks (space-to-Earth) and uplinks (Earth-to-space) -- close enough to the 1.612 GHz astrophysically abundant hydroxyl radical (OH) to worry radio astronomers about interference from adjacent bands (Feder, 1996). Motorola is promising to limit spillover, but the issue underscores that the microwave spectrum is a limited resource jealously guarded by commercial and nonprofit users alike.

Proponents of Space Power recognize that frequency allocation must be addressed promptly and effectively to avoid pre-emption of the technology before it's born. Clearly, uplink and downlink frequencies should be chosen to minimize interference with other applications consistent with high transmission efficiency through the atmosphere. But rather than compete with communication for the microwave spectrum, we propose that comsat and powerbeam functions share the same frequency by modulating the powerbeam to provide downlink data transfer. Commonalty of frequency could is a powerful argument in favor of licensing integrated communications/space power systems. In Figure 7, we illustrate schematically how a standard SPS rectenna could be modified to extract an encoded communications signal prior to rectification of carrier power beam.

THE FINAL FRONTIER, FINALLY?

What we proposed here is a low-mass, possibly inflatable, solar power satellite which could function in a dual mode as a communication satellite. The mother of this invention is the need to provide a revenue-generating bridge to large scale Space Power. In an evolutionary mode, the first function of an

integrated solar panel-transmitter might be to power the communication function only. What we envision as a first step is a wireless system in which ground stations are powered by the beam in the same way that wire-connected telephones are powered by line current.
Given the interest in multimedia satellite communication systems, such self-powered microwave beam transmitting satellites might be marketable today. In future scale-ups, the power transmission function would be expanded and exploited commercially. Our goal is to evolve the infrastructure of space power in a systematic pay-as-you-go way that builds on current projects in satellite communications.

An obvious question is whether there is evidence that telecommunications or electric utility companies would want to enter the Space Power business. The answer is no, there is no evidence. But that is only because these industries are unaware of the commercial possibilities. One has to know that an option exists to choose it. Once feasibility is shown, and a respected player takes the plunge, feeding frenzies by investors show up in the most unlikely places -- witness the Internet and Comsats. It is the nature of the capitalist system.

For reasons having more to do with politics than with science or engineering, national research and development establishments have remained cool to SPS since the 1970s. Despite obvious problems with controlled thermonuclear fusion research, it continues worldwide at the $1 billion/year level; while only token funding is allotted to SPS. In the U.S., Space Power remains the weakest of blips of NASA's radar. Nor has the Department of Energy taken up the challenge of researching innovative carbon-free energy sources for the next century, despite the finding by the Intergovernmental Panel on Climate Change that humankind's CO_2 emissions can transform our planet's climate in the twenty first century. It may be that fossil fuels are so deeply embedded in the global infrastructure that the only way to displace them is to lay down an alternate infrastructure through an entirely different industrial base.

What is certain is that the present era of government deregulation in the U.S. has led to a scramble on the part of telecommunications, computer, cable TV, and utilities industries to enter each others markets -- particularly as regards the so-called information superhighway. A recent article in the Electric Power Research Institute (EPRI) Journal reports that "EPRI believes that utilities should consider more aggressive involvement in the information revolution, adding fibre-optic cables to their already far-reaching power delivery infrastructure and partnering with other investors to take an ownership role in the systems now being developed" (Jaret, 1995). The electric power companies are clearly interested in entering the communications business. What we are proposing is an inversion of this logic in which communications companies could enter the power business. In practice, it may be more practical for consortiums of power and communications companies to develop the proposed technology -- but that remains to be seen.

Even in the U.S., there are large regional variations in the cost of electricity stemming from the finite resistivity of power lines (Figure 8). This is even more true internationally. There is a major trend toward international long-distance electrical transmission systems that would make power available where it is needed from where it can be produced (Pearce, 1995). Early on, it was recognized by the brilliant American architect and futurologist R. Buckminster Fuller that the Earth's renewable resources might be linked to centers of populations by intercontinental electricity grids. Fuller's idea is also shown in Figure 8. Vice-President Al Gore, well-known for his environmental concerns, has said, "A global energy network makes enormous sense if we are to meet global energy needs with a minimal impact on the world's environment." And most certainly, the Space Power constellations proposed here would serve a similar function, particularly for energy-hungry tropical developing nations.

In a recent Scientific American article, the president of Teledesic argued that "satellite communications may help stem the large scale migration of people from the countryside to cites and from the developing world to developed nations" (Dagget, 1995). That may be the case, in time. But at this point most of these nations lack the infrastructure and resources to employ multimedia communication products on a large scale. It is highly unlikely that developing nations can leap from preindustrial to postindustrial without a substantial increase in per capita energy consumption. What they need now is affordable carbon-free electric power that does not require excessive land use.

Apart from costs, which must, of course, be competitive, there are two fundamental advantages of Space Power relative to terrestrial renewable non-CO_2 energy sources: (1) The electric power per unit surface area devoted to the energy source is much greater for SPS -- by a factor of ten according to our estimates. And as noted previously, visually transparent rectennas permitting crop growth and grazing further reduce the land use requirements of SPS. This means more land can be spared for human agriculture and natural ecosystems. (2) Electric power requirements tend to be continuous and concentrated in regions of dense human habitation, whereas terrestrial renewables are intermittent and remote from their end use demand. This means global transmission grids are needed -- which have their own cost, technology and environmental obstacles to overcome.

In principle, all terrestrial renewables pose environmental problems because of their relatively large land use requirements. Hydropower, the most exploited renewable thus far, has produced significant disruption of ecosystems and human habits by flooding previously occupied areas. Solar, biomass and wind farms would similarly compete with people, agriculture and natural ecosystems for land were they basis of a global energy system.

Perhaps the most important question we should be asking is how to best supply the energy needs of ten billion people fifty year hence with the least adverse impact on the environment? SPS offers a vision is which energy production moves off the Earth's surface; and consequently we live on a "greener" planet. Consider the philosophical implications: No longer need humankind see itself trapped on Spaceship Earth with limited resources, but now the resources of space are open to economic expansion -- with the Earth preserved as a priceless resource of biodiversity. There is still a way to go. But, as Lao-tzu put it, "A journey of a thousand miles begins with a single step."

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FIGURES

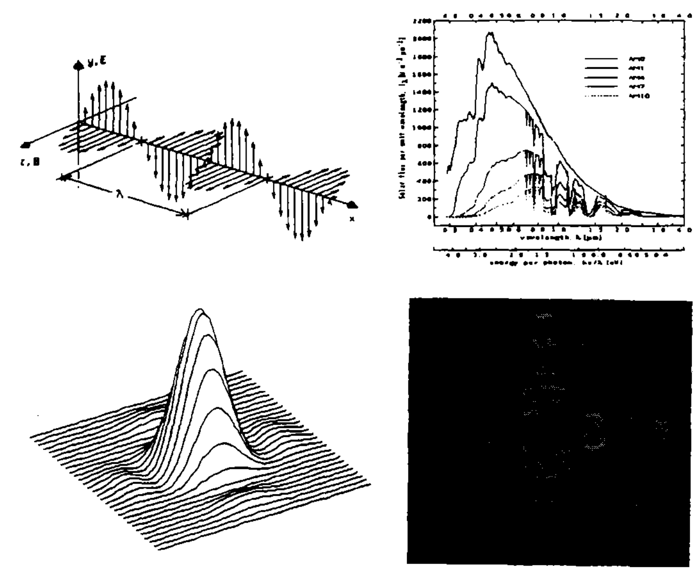


FIG. 1. ELECTROMAGNETIC RADIATION AND DIFFRACTION. (TOP LEFT) Power is transmitted through space normal to the plane formed by orthogonal electric and magnetic waves. (TOP RIGHT) Radiant power is produced over a spectrum of wavelengths by the sun, some of which is absorbed by the Earth's atmosphere. (BOTTOM LEFT) Coherent EM radiation can be generated at specific wavelengths by oscillators or lasers transmitting through an antenna or lens aperture. The power intensity pattern shown is for a rectangular aperture (Hoffert et al., 1989); most of the power is contained by the main lobe, which spreads with increasing distance by diffraction at an angle proportional to the ratio of wavelength to source aperture. (BOTTOM RIGHT) Diffraction pattern of a light source through a rectangular slit recorded on a photographic plate showing overexposed main lobe and sidelobe patterns (Born and Wolf, 1980). An SPS converts EM power in the solar spectrum at the top of the atmosphere to focused EM microwave or laser beam power for reception and conversion to electric power at the Earth's surface.

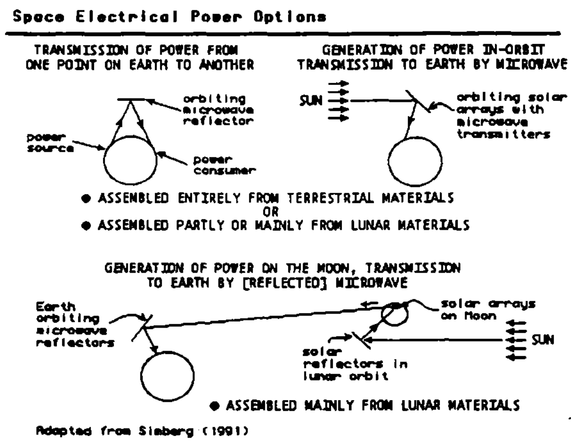


FIG. 2. THREE CONFIGURATIONS FOR SPACE ELECTRICAL POWER. (TOP LEFT) Power Relay Satellites (PRS) convey terrestrial energy to distant points on Earth by bouncing microwaves off reflector satellites in Low Earth Orbit (LEO). (TOP RIGHT) Earth orbiting Solar Power Satellites (SPS) transmitting solar power to the surface. This category include the geostationary SPS Reference Design of the 1970s and constellations of integrated communication/powerbeam satellites in LEO proposed here. (BOTTOM) The Lunar Power System (LPS) takes advantage of the lunar surface as a platform for solar collectors and lunar materials for fabrication, transmitting power in tight beams to relay satellites convey the power to ground stations on Earth.

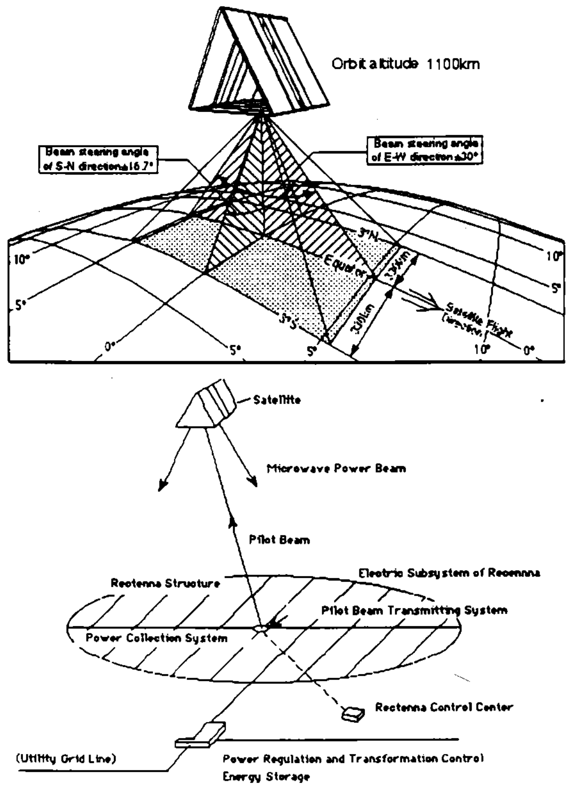


FIG. 3. SPS 2000. (TOP) Triangular cross-section demonstration SPS proposed by Institute of Space and Astronautical Science of Yoshinodai, Japan. Sunlight collected by photovoltaic cells on the upward faces of this kite-like satellite is converted to microwave energy in a powerbeam steered by phased-array transmitter on the Earthward face. Orientation is maintained by gravity-gradient stabilization. The equatorial orbit could provide a demonstration of a novel carbon-free electric power supply to tropical, developing nations where it is most needed. (BOTTOM) Overall SPS 2000 system including receiving rectenna and uplink pilot beam (Nagatomo et al., 1993).

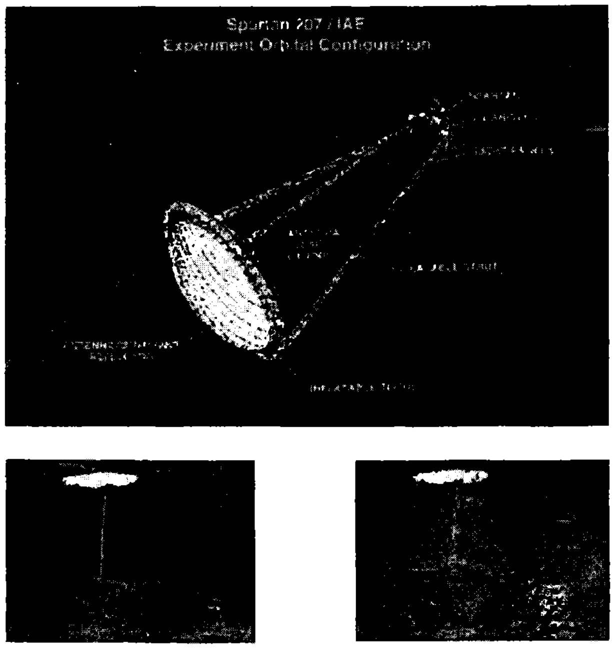
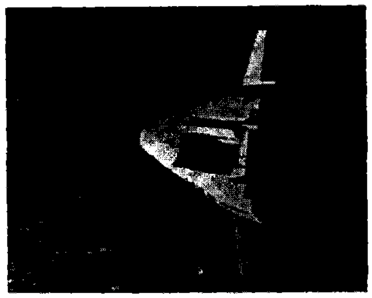
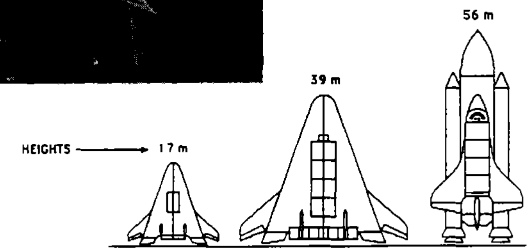


FIG. 4. SPARTAN INFLATABLE ANTENNA EXPERIMENT (IAE): (TOP) An inflatable antenna 50 feet (14 meters) mounted on three 92-foot (28 meter) struts. The struts are attached to the Spartan spacecraft, deployed and then recovered by the Space Shuttle. In LEO, the Spartan becomes a platform for the antenna which, when inflated in space, is roughly the size of a tennis court. (BOTTOM) Spartan overflying the Grand Canyon as viewed by Space Shuttle Endeavor astronauts. (NASA images downloaded from World Wide Web site: http://sspp.gsfc.nasa.gov/sp207.html).





	TEST MODEL X-33	FULL-SCALE SHUTTLE Venture Star	PRESENT SPACE SHUTTLE
Estimated cost to carry cargo	Not applicable	GOAL: $2,200 per kilogram	$22,000 per kilogram
Risk of catastrophic failure	Not applicable	GOAL: At least 10 times less risky than current shuttles	1 in 145 flights in 1995 for all shuttles
Payload bay size	1.5 m x 3.0 m	4.6 m x 13.7 m	4.6 m x 18.3 m
Gross liftoff mass	124,000 kg	992,000 kg	2,064,000 kg

FIG. 5. ROCKET SCIENCE. (TOP) Venture Star, a Single-Stage-to-Orbit (SSTO) vehicle proposed by Lockheed-Martin Skunk Works of Palmdale, CA, to reduce launch costs is shown deploying a satellite in an artist's rendition. (BOTTOM) Comparison of the NASA X-33 test vehicle with the eventual full-scale Venture Star and the present Space Shuttle. Payload launch costs in the $2000/kg range can make Space Power cost effective if low-mass SPS technology can achieve specific power $\geq$ 1 kW/kg. But lower specific power could likewise be cost effective if revenue is produced by information transfers along with power transmissions.

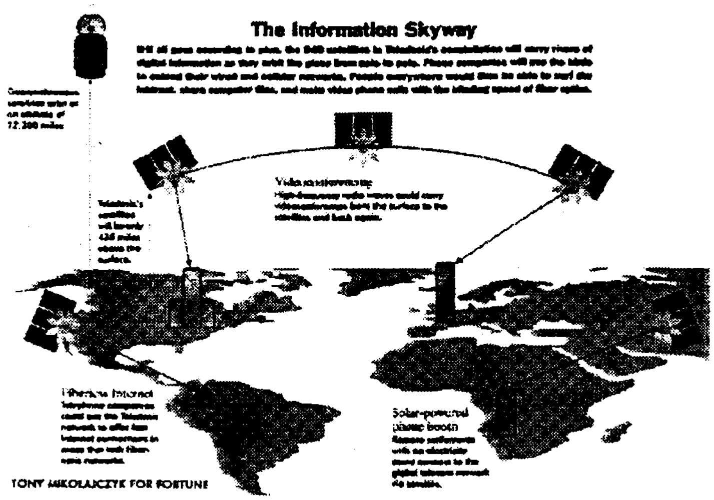


FIG. 6. TELEDESIC COMMUNICATIONS SATELLITE SYSTEM. At an altitude of 435 miles (700 km), 21 rings of 40 satellites apiece, or 840 in all, permit at least two satellites to be accessible to everyone in the world at all times. Onboard software choreographs a grand celestial dance. The satellites circle in polar orbits from north to south. Each will be linked electronically with eight neighbors in a geodesic pattern across the sky. As it moves out of range of an earthbound user, a satellite will hand off the radio signal to its nearest partner, sometimes in an adjacent ring, sometimes rising from behind. The concentric orbits do converge at the poles, but the satellites are at slightly staggered elevations and will slip safely past each other, with thrusters ejecting out tiny particles of Teflon to make delicate adjustments in direction (from Kupfer and Davis, 1996).

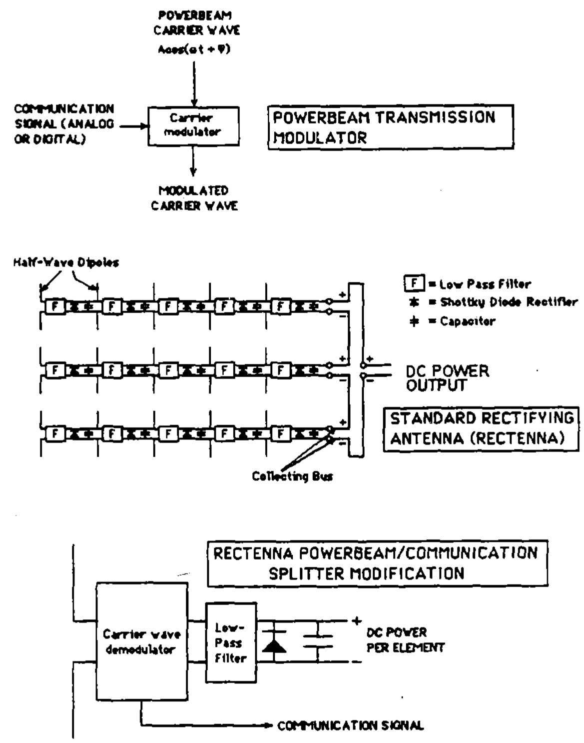


FIG. 7. INTEGRATING POWERBEAM AND COMMUNICATIONS FUNCTIONS. (TOP) Modulation of SPS powerbeam carrier wave to carry information; (MIDDLE) Standard rectenna configuration for power reception and conversion to DC (Brown, 1984); (BOTTOM) Proposed conversion of rectenna elements to dual mode (power/communications) function. Uplink information transfer is standard for communication satellites (Gagliardi, 1991). Such dual mode modifications would permit Space Power delivery to be gradually integrated into the infrastructure of LEO communication satellite constellations such as Teledesic or Iridium.

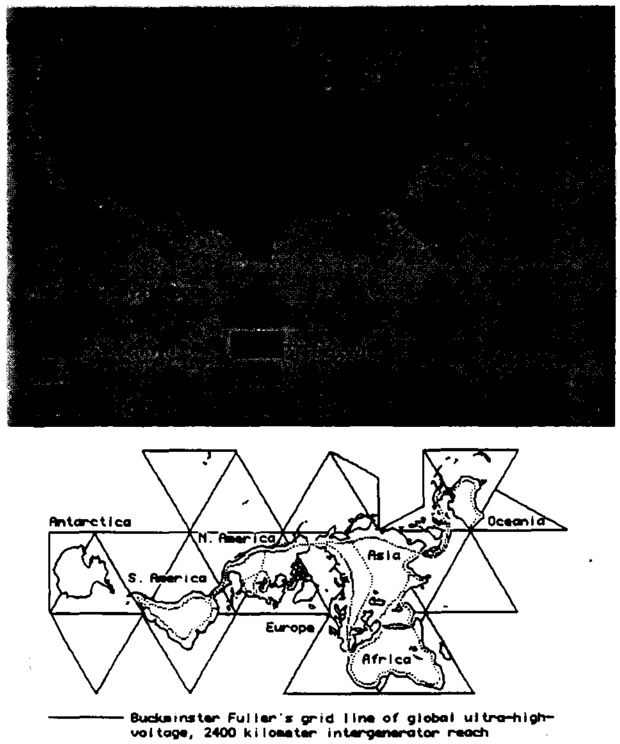


FIG. 8 (TOP) ELECTRICITY PRICES BY STATE. Major regional variations exist in the Cost of Electricity in the US and worldwide because resistance losses in power lines prohibits economical long-distance power transmission (Douglas, 1995). (BOTTOM) GLOBAL GRID. The advantages of a planetary-scale electricity delivery system for the global market prompted Buckminster Fuller decades ago to propose a global superconducting power grid (Fuller, 1981). Today, by exploiting state-of-the art technology, opportunities exist for entrepreneurs to develop space-based electrical power as a global commodity. We argue here that a cost-effective path way to do this is by integration of space electric power delivery services with satellite telecommunications networks.

Next, Dr. Lewis.

Mr. LEWIS. Thank you, Mr. Chairman. We are at the threshold of a new century that is beginning with space travel, hypersonic aviation, nuclear power, electric automobiles, genetic engineering, global cellular phone service and personal computers. This coming century will be a time of unprecedented change.

It is harder to foresee the events of this next century than it was for our grandparents in 1900 to foresee the world as it is today, and I don't think I need to remind you, they did a terrible job of that. Where will we be at the end of the next century? Linear extrapolations of what we are doing now don't work. Things can't go on like this and they never have. Everything is going to be different and I will give a few brief examples.

I will try not to use the accepted redefinition of 5 minutes that some others have used and try to keep it within the real 5 minutes. Let me first remind you that American planetary exploration missions to Mars and Venus have already taught us about the devastating effects of chlorine and water vapor on the ozone layer. Because of this knowledge, we chose not to build a high altitude supersonic transport and we drastically curtailed our production of chlorofluorocarbons.

As a result, the ozone layer will repair itself over the next few decades and there will not be a global plague of skin cancer and not be global killing of seedling wheat and rice by ultraviolet sunlight. We solved these problems, which we did not know existed as problems, by doing basic solar system research and bringing it home to Earth. Critical discoveries were made by the American Mariner spacecraft to Mars and Venus.

Trying to look ahead to decide what we need to develop in the next century places us in the same position we would have been in in the 1950's if we had tried to anticipate the threat to the ozone layer. We can identify three areas of enormous importance that are now emerging, with even more profound implications for the future than the example that I gave you from our past.

First, these, as you have heard, is the lowering of launch costs, using new technology boosters, airline style operations and free and open competition between companies offering launch services. The second, which you have not heard about, is the discovery and characterization of Earth threatening comets and asteroids to predict the potential collisions with Earth and to give us a central knowledge of their physical and chemical properties.

The third is the proliferation of micro and nanoelectronics to permit automated manufacture of vast numbers of tiny machines to serve mankind, and also to permit safe automated exploration and exploitation of very hostile alien environments. The synergism of these newly emerging capabilities will permit astonishing increases in human ability to manipulate matter and energy and thereby shape our future and change our visions of the possible launch cost decreases, give us the ability to build solar power satellites economically, offering us, as Potter has told us, cheap, clean abundant, electrical power, combined with the knowledge of and access to near Earth asteroids, and with autonomous and tele-operated processing equipment, we could capture metals from Earth threatening asteroids into the Earth's orbit.

With a leverage of 100 to 1, mission studies that have been done show that for each ton of equipment devoted to retrieval of material from near-Earth asteroids, you can return 100 tons of structural metals or propellants to the vicinity of Earth. By so doing, we can build solar power satellites at a greatly reduced cost, even below those that have been considered in NASA-funded studies to date by further minimizing the mass of equipment that must be launched out of the Earth's deep gravity well at enormous launch costs.

Cheap, abundant, clean electrical power, as Dr. Potter told you, offers us a number of features that I will not do more than mention in passing. First, energy independence from foreign sources of supply, a strategic issue of the first importance for the next century. Enormously diminished environmental impact of our energy supply, compared to, for example, supertanker fleets, radioactive waste, strip mining for coal, these will no longer be needed in what have always been continually increasing numbers.

And as a further environmental benefit, we will see a way out of the global warming problem caused by fossil fuel combustion. In addition, electrical power delivered by these solar-powered satellites, without the intervention of fossil fuel-burning makes electrical power available for surface vehicles with very small environmental impact. It also makes hydrogen available by electrolysis of water which empowers high performance aircraft of the future and we don't even need hydrocarbons to fly our aircraft fleets in the future.

It permits a phase down of hydrocarbon production, extending our supply a few decades, or at the current use rates, indefinitely for use as a valuable industrial feed start. The high technology contributions of nanotechnology and tailored microorganisms will permit us to do processing, biological and physical processing and chemical processing in vast areas of industry here, Earthside, as well as in space, anything that involves the need for searching, recycling, sorting, processing or fabricating enormous masses of material.

Machines that are at least partially self-replicating, based on computer technology that has grown out of the space program, will permit these tiny robots to produce themselves in profusion, greatly increasing the amount of productivity per human worker. They could gather manganese modules from the ocean floor, sort our garbage for recycling, extract rocket propellants from the atmosphere of Mars or the surface of the Moon. They could mine construction metals from nearby asteroids, bodies which, if not used up, would eventually collide with Earth.

These international and interplanetary endeavors demand an educated work force, competent, of course, in math and science and in engineering, but also in languages and law and economics and management and so on. These are essential ingredients of our future and any nation which fails to understand the underlying importance of exploration, research and education will remain firmly stuck in the 20th century.

We are not trying to plan the futures of our descendents, but we are trying to open their options. Resource limitations, as usually discussed, reflect merely the technologies we have available to us. Space technology makes vast new resources accessible to us.

Let me give you one example. There is a near-Earth asteroid called Amun, A-M-U-N, that crosses the Earth's orbit twice in each trip around the Sun. It is about 1,000 yards in diameter. It contains more iron and steel than the total production of every nation on Earth for all of history. The market value of the metals in Amun, about $5 trillion, and it is the smallest known metallic asteroid out of many dozens known. It is more accessible to us or approximately as accessible as the surface of the Moon. It is about as easy to get to in terms of rocket power and rocket compulsion requirements as the surface of the Moon and easier to get back from.

In the asteroid belt, we have countless dozens of asteroids much larger than Amun also made of metals. If we ask how many people could be supported by the known resources of the Asteroid Belt, in a recycling regime in which material is kept in circulation, the answer is an astonishing 10 quadrillion people. The known resources of the Belt are sufficient to support indefinitely a population 1 million times the ultimate carrying capacity of Earth.

When we think about, for example, using the resources of the Belt to help make Mars habitable, as Buzz Aldrin commented, let me tell you what would happen if you brought the metals of the Belt to Mars. You would be able to build a steel frame building 80,000 feet tall covering every square inch of the surface of Mars.

In other words, the resources necessary for terraforming planets are a trivial, minuscule fraction of the wealth of resources available to us in the Belt. Any processing plant in place upon Earth-crossing asteroids gets a ride out of the Belt on every single trip around the Sun. It automatically goes out to the Asteroid Belt. These space resources, both the energy resources that Dr. Potter talked about and the material resources, are available to us if we use space science and technology to access them. It is up to us, and I would like to close with a quotation that goes back almost exactly 100 years to H.G. Wells, looking at this century, he said, "The choice is the universe or nothing."

Mr. Weldon. I want to thank you, Dr. Lewis. That was a very intriguing and enlightening and global presentation to wrap up this panel.

I guess to kick off the questioning, let me start with Joshua. We began with you, I guess, almost an hour ago, and what did you think of this presentation that came after you? A lot of us here in this room are going to be looking to your generation to implement some of these things, so what are your thoughts on going to the Moon, going back to the Moon, going to Mars, space-based energy resources, what did you think of the panel?

Mr. OUELLETTE. Well, I have always been very interested in the sciences, so from that standpoint, it was fascinating. The way that I am viewing this is they are building it. I am going to fly it, I, referring to kids my age and younger. But this is actually some of the first real encouraging things I have heard on the space program in a long time, especially with Dr. Zurbin's ideas on how to make it far less expensive in colonizing the Mars martian planet within a relatively short span of time. From that standpoint it excites me a lot.

Mr. Weldon. Let me just ask you, I am not sure if you mentioned this in your presentation. What is the first thing you remember about the space program as a young man growing up? Do you have a first recollection of something that intrigued you or excited you about NASA or the shuttle or Apollo or anything that you can think of?

Mr. OUELLETTE. I mean, of course, it is mainly the shuttle because the shuttle was the only thing I have ever seen launched. I mean, the Apollo missions all took place a long time before me. I mean, I was born in 1981 and the last Apollo mission ended 9 years earlier. But it is definitely the space shuttle. It is obviously a very powerful tool. It has a lot of uses, but I do also, on that note, think that we need to move beyond the space shuttle.

The space shuttle has kept our space program going for several decades, but its uses are, as some people have mentioned before me, limited to going around in circles and it is less the space shuttle itself and more of what happens when you stop going around in circles that has interested me all my life.

Mr. Weldon. Do you think we should go back to Mars—have never been there. Do you think we should send a manned mission to Mars, I guess is the question.

Mr. OUELLETTE. Definitely. In some ways, I like the idea of thinking of it as an insurance policy, especially now that we have all seen the Shoemaker-Levy comet plummet into Jupiter that would have annihilated the Earth like nothing, and from that standpoint, it is incredibly important, just to the survival of us as a species. But I think it is also incredibly important to our survival as a Nation.

I mean, what probably got us through the cold war without the cold war becoming a hot war, world war III, was probably the space program. That was a constructive, rather than destructive aspect of it. And even from an economic standpoint, I mean, we have heard mentioned that one near-Earth asteroid could basically pay off our national debt, imagine what going to Mars can do. With commerce between the planets, sending back raw materials, even moving some of our heavy industry to Mars, in ways, basically, there isn't—the way I think about it is there isn't anything to destroy on Mars with our heavy industry. It is probably the most important event in human history as far as I am concerned.

Mr. Weldon. Dr. Potter, I was very interested in your presentation on generating electricity in space. We had, in the panel last week, two scientists who talked about generating the power on the Moon, and then beaming it to satellites in the Earth's orbit that then transmit it down to the surface of the planet. How is that different from what you are talking about, and what are the pros and cons of the two different concepts as you see it?

Mr. POTTER. You are probably talking about Dr. Criswell's idea.

Mr. Weldon. Yes.

Mr. POTTER. And I know him reasonably well and I think the main difference is one of time. The idea that I am suggesting, that is satellites in low to middle Earth orbit, is something we can do right now. Because of the sheer amount of power that the world is going to need during the next 50 to 100 years, eventually I feel we will need to go to higher orbits. We may need to go to the Moon, so it is a question of how much versus how long.

Mr. WELDON. And do you think that we could develop today a system like you are talking about and a low-Earth orbit, providing electricity to a city or a Nation or a community.

Mr. POTTER. I feel we could start this afternoon, if we had to, and we could probably have something ready within, say, 5 years.

Mr. Weldon. Do you think there is a role for NASA to be involved in the initial phases of such a program or would you recommend that be handled by the private sector, like a consortium of power companies handling it.

Mr. POTTER. I feel there is definitely a role for NASA in doing what government has always done best and it was alluded to by one of the other panelists, taking the risk out. I think once this idea is proven, there is going to be a feeding frenzy and communications companies, utilities, companies whose existence that we can't even predict will emerge.

Nobody predicted Internet service providers 10 years ago. But the role of NASA should be perhaps to use some of its existing capability. Something like a long duration exposure facility, right on the international space station that could be tended to by astronauts as needed. I should say a prominent Russian aerospace engineer, who I can't mention at this point, did express interests in such an idea, so there is definitely a role for NASA.

Mr. Weldon. OK. I would like to now recognize the gentleman from Texas, Mr. Turner, for questioning.

Mr. TURNER. Thank you. I want to commend Joshua for his presentation today. Joshua, I had the good fortune of representing the Woodlands in the State Senate a few years ago and my congressional district now comes within about 10 or 15 miles of your home, and so I can't take the credit for you being here today. Your Congressman, Kevin Brady, is a good friend of mine and I know he is proud that you are here today testifying on behalf of the young people, because you truly are an outstanding representative of the young people in this country, and in many ways, it is inspirational to us to see you here because the things we are talking about and doing are really things that will be greatly meaningful to you in your generation, and I think it is our responsibility to be sure that we do the right things, to be sure that your generation is able to benefit from our decisions.

You know, I listened this morning with great interest, and it continues to, I guess, cross my mind as one of the panelists suggested, that we ask NASA to lay out a definition of a mission, so that we can place it on the President's desk in 2001 and begin to mobilize the Nation in a specific direction. I guess I would welcome any of the panelists comments on this because I think it is critical, even though, as I said to the earlier panel, none of us are great fans of blue ribbon commissions, many reports are done and prepared and bound up neatly and find they are not paid a whole lot of attention to. Obviously we wouldn't want to repeat that kind of process in something as important as our future in space exploration. But it does seem to me that it is important, not just to have NASA lay on the table the direction of the space exploration program for this country, but to bring all sectors, public and private, together, in a way that we really can develop a national consensus.

After all, one of the problems I think we face today is that our space program has matured somewhat and many people looked at NASA as just another government agency, and it wasn't looked upon that way in the sixties, when we had the excitement of the early days of the space program and so it may take more consensus building to put us on the road to exploring Mars, and I would welcome any comments and suggestions that any of you may have about how we might develop that consensus that will put us on the right track.

Mr. ROGERS. You won't be able to, is my view, my judgment. I tried for 15 years. President Bush tried very hard. There has been study after study, commission after commission. It doesn't work. There was one day when I was asked to meet with Salley Ride after the SEI study. She had been asked by the NASA Administrator to see if she could think of a way to move ahead. And she asked me would I review her report and I said let me ask you a few questions first. Who have you been talking to. She said Professor Jones, Dean Smith, and some of them I know.

I said is the problem one of finding smart, highly educated, highly motivated people to spend the money to go to the Moon and Mars or is the problem to get authorization and appropriations? She said the latter, of course. Well, I said, tell me again, who have you been talking to? That is the question. You will have a broad enough group of people willing to say, yes, let's go to the Moon and Mars, providing they don't have to pay for it, and that is why I made the suggestion that I did this morning.

I don't know that Bob Zubrin is ready to break out in tears, but we discussed how to get to the Moon and Mars on a number of occasions and this is the first time I have been able to say, in all honesty, that I think there is a way to get there. The way to get there is to say, let us put a line item in the NASA budget. Let's start, and now let's fund it in proportion to what the life space flight area generates in private sector revenues and taxes. That immediately tells you that the public doesn't have to pay anything for it because there are those taxes and revenues being generated today, and it says NASA is now challenged to go out and create, create the sustenance for meeting its own desires.

One of the great difficulties, going back to what I said at the beginning of the Federal Civil Space Program today, is it doesn't capture nearly well enough the national interest in civil space. People think they are the same thing and they are not. If we can bring together the very, very smart scientists, technology developers, engineers, within NASA, the aerospace industry and related universities, marching toward the Moon, Mars, at the same time that we say you will get there as fast, as fast as you can help our private sector to generate the revenues and generate the tax base for so doing. That is my view.

Mr. ZUBRIN. I have to agree in part with Mr. Rogers that the national commission, blue ribbon commission, is of limited value. Although, as Buzz pointed out earlier today, the Payne report was an exception to that, in that it was sort of a remarkable document that could have kicked something off had it not landed in the middle of the *Challenger* disaster. But there is no shortage of support in this country for a Humans-to-Mars program. I can speak to that directly.

I have had the experience of going around and giving talks on Humans-to-Mars program, not just to space societies and engineering groups, but to rotary clubs, plumbers conventions and you name it. And the main question I get at a conclusion of a talk about Humans to Mars and how and why we can do it is how come we are not doing it? People come up to me and say I remember Apollo. That was great. Weren't we supposed to go to Mars after that? How come there was no follow through?

This is the sort of thing this country ought to be doing. In fact, there is immense ground swell. There is, in fact, a feeling of betrayal among people in this country, that it seems as if the government has accepted this notion that this country has entered the age of limits in which we are no longer capable of doing stuff like this.

Well, we are capable of doing stuff like this, OK. We are richer than we were in the 1960's, a lot richer. We have a lot larger GNP and we are not facing an adversary of incredible strength, and there has never been a country as rich as we are today and the challenge to us to undertake sending humans to Mars today of all its risks is actually of a lower order than the challenge was to send humans to the Moon in the 1960's when we had to start from scratch. So we can do it. The popular will is there.

What we need is some political leadership. And what I was saying, when I said tell NASA to do phase A, I meant that. I did not mean tell NASA to come up with their vision statement for the first decade in the 21st century because they will tell people whatever they think someone wants to hear or whatever. I mean for Congress to tell NASA, I want you to come up with a plan, a low cost plan to have humans on Mars within 10 years, and I want you to be able to submit that to the President-elect in November 2000, and do it.

In other words, the marching orders really have to come from the politicians. The Apollo Program did not come from NASA. It came from Kennedy, and, similarly, getting humans to Mars is not going to come from NASA. It has to come from you, and so it is necessary, and obviously there are people higher ranking than individual Congressmen or Committee chairman or so forth that have to be brought in, and in the executive branch as well, but this is what needs to be put together.

A piece of political engineering has to be put together and I believe that since nobody knows who is going to be President in November 2000, that—whether it is going to be a Democrat or Republican or which particular individual it is going to be, I think an agreement now, to put that in motion, to give that person, whoever he is and whichever party he is, the option to undertake that step could conceivably have bipartisan support, in a way it could not, after that has been decided, so that is what I think we need to do.

Mr. Weldon. Well, I just have a few followup questions I would like to direct, and, actually, they are specifically to you, Dr. Zurbin. One of the big questions that is always asked is why don't we send robots to Mars instead of people to Mars? Can you just tell us how you answer that question? I am sure you get asked that question as well.

Mr. ZUBRIN. Sure. There are two answers to that. Of course, this came up a great deal after the discovery of the Mars rocks with evidence of life in them last summer, OK. And don't get me wrong, I do not oppose sending robots to Mars. In fact, I think the current sending of robots to Mars is the most productive thing NASA is doing at the moment. However, it is not enough.

First of all, obviously the robots are not settling Mars, they are just there to do scientific work, and if we are looking for evidence of life on Mars, if we are fossil hunting on Mars, which is what the mission is, look at what you have to do to do fossil hunting on Earth. You have to hike long distances through unimproved terrain, you have to be able to climb up steep hillsides. You have to be able to do heavy work like pick-ax work and digging. You have to be able to do delicate work, pealing open fossil shells, which are like books made of rock which have to be carefully split open to see the evidence that has been pasted inside.

You have to exercise very subtle forms of perception and intuition. This is all far beyond the capability of robotic rovers. You cannot hunt for fossils with toy cars. If you took a rover, like the one they are landing on Mars this summer, the Sojourner rover, which is like a toy car with wheels 6 inches in diameter, it cannot climb over a rock 1 foot high. It cannot get out of sight of the lander and it has no manipulative abilities.

If you landed one of them in the Rockies—if you landed 100 of them in the Rockies, you would never find a dinosaur fossil, despite the fact that the Rockies are bound in dinosaur fossils. If we are going to get the answer to whether there was life on Mars and also to determine to any realistic effect as to how far it evolved, we are going to have to send real life human explorers, real live rock hounds. But what is more to the point is, if we understand that Mars is not just an object of scientific inquiry, it is a world, a world with all the resources required to create a new branch of human civilization, that can only be tackled by humans.

Mr. CARPENTER. Mr. Chairman, may I overstep my limits as a member of the defunct committee to get a defunct panel to give an answer to your question? It came from Tom Stafford a long time ago, Tom Stafford of Apollo. He made note of the fact that in order to have a meaningful and vigorous space program, we must enlist the support of the people of this Nation, and he said who gives a parade for a robot?

Mr. WELDON. Good point. Thank you very much.

Let me ask Dr. Lewis a question regarding Dr. Zurbin's proposal to put a nuclear reactor on Mars? Occasionally, on the Space Coast, we launch probes and satellites that have nuclear reactors on them and there is always a pretty high degree of concern. I would think the type of reactor Dr. Zurbin would be talking about launching would be something a little bit larger. You express some real concerns about the environment and protecting the environment. Do you have a problem with putting nuclear reactors in space, launching them from the Cape, sending them to Mars?

Mr. LEWIS. Launching a live, fully fueled nuclear reactor is folly, but there is no necessity to do that. A nuclear reactor can be launched without its fuel rods inserted. In fact, it can be launched in a completely inert configuration, and protected in such a way that even if the booster would fail, when it reentered the atmosphere, it would do so intact.

I should point out, however, that if environmental considerations prevented from launching a reactor, you could still achieve the goals of this mission with a rather different design using solar power.

Solar power can be used on Mars. You need to be cognizant of the existence of dust storms, and you need to allow for cleaning off the solar cells, but you could do that if it were necessary. It seems unlikely to me that the people who design Mars missions are going to have the final word on whether it is nuclear powered or not.

Mr. Weldon. Do you have any rebuttal to some of those comments he made?

Mr. ZUBRIN. Well, first of all, if you take a nuclear reactor that has never been used, it has a much lower radioactive inventory than the RTG's that we have launched from the Cape already, such as the one on Galileo or Voyager. So, if you have the control rods in there and locked into place, it cannot go critical. In fact, while I am sure that there will be various activist groups that will demonstrate and go to court and whatever to oppose the launching of a nuclear reactor from Florida, the rational grounds behind their complaint are actually of a lower order than the very limited basis for their objections to the launching of the RTG.

The use of solar power on Mars is possible, I don't dispute that. It does add weight to the mission. It is true, as John says, that you could do a mission of the type that I described with solar power. However, it would increase the mass and the cost.

Captain CERNAN. Mr. Chairman, there is a precedence already set. Twenty-five years ago on *Apollo 17* we carried a nuclear reactor. I personally fueled it on the surface of the Moon. It operated flawlessly and harmlessly for over 10 years, sending back information. It finally had to be shut down because of a cut in funding.

Mr. Weldon. Thank you for sharing that. I want to thank each and every one of the panel members this morning for your very fascinating testimony. I realize that many of you had much, much more to share than you were capable of doing within the time constraints, but we really do appreciate you coming, and the meeting now stands adjourned.

[Whereupon, at 12:17 p.m., the subcommittee was adjourned.]

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