

MIT FORUM ON THE FUTURE OF HUMAN SPACEFLIGHT

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Welcome and Introduction

Professor David Mindell, Director, MIT Program in Science, Technology, and Society

Good Morning. Thank you all for coming. We really appreciate not only such a good turn out as numbers but such an interesting and diverse crowd from this community. My name is David Mindell. I'm a professor at MIT and the director of the Space Policy and Society Research Group. I'm just going to give you a little bit of introduction and a little bit of background on both the white paper and this forum and where it comes from and a little bit about our goals before turning it over to our panelists.

I'm actually half an historian and half an engineer, and for twenty years I worked in the undersea deep-ocean exploration business where I became permanently fascinated with the relationships between man systems, remote systems, and autonomous systems and how the interactions surrounding those things for doing science and also for doing exploration were never quite as simple as we thought they were when we first started building them, and as an historian I've been studying that issue for about the same period of time actually most recently in a book called *Digital Apollo* on the lunar landing and the automation and the computers and the software for the six Apollo landings.

This group—the Space Policy and Society Group, which you'll hear many of our members from—formed probably about five years ago. It really started with a dinner that happened when John Logsdon was in town with Jeff Hoffman and Dava Newman and Larry Young and myself and a couple other people thinking about ways that MIT might be able to contribute in the space policy world. Following that came a generous gift from the Shapiro Fund, an alumni of MIT who will be here later, which allowed us to develop the study that became the white paper as a sort of policy statement to address what everyone in this room I'm sure is aware of as this major forty-year moment in the history of U.S. human spaceflight. Over the past few years we invited a long series of guests to MIT, some of whom are here in this room, people from NASA officials to contractors, public affairs type people from NASA, people from DC policy circles, and just began listening and talking and hearing a lot of different opinions and at some point we decided that we had something to say on this topic and about a year ago began developing what became this white paper, which is actually not white, in the short version last December, very consciously timed at the transition, well roughly timed at the transition, the shuttle transition but specifically timed at the transition between administrations. Also in the course of this year our colleague Scott Pace left NASA and joined George Washington taking over from John as the director of the Space Policy Institute and we saw there a new collaboration between MIT and the Aero-Astro

department, my own program Space Policy, sorry Science, Technology, and Society, as well as the Technology and Policy program at MIT which Dava Newman, who's here, directs.

Before I address the content of today's conversation, I want to begin with a little bit of thanks. First of all Denise Zheng from CSIS and Jim Lewis who've very graciously served as our hosts for this forum. Alison Fox from the MIT Washington Office who really helped us with some our remote presence down here in DC from Cambridge. Also all of the many guests who we've had at MIT over the last several years who've been eager to kick these ideas around with us and very open in all cases to some new thinking, some radical thinking, hopefully some controversial thinking. Dennis Shapiro and the Shapiro Fund, whose gift really allowed us to take on this study and study these issues truly independently. We have no agenda other than our own professional judgments and conclusions, which I've learned is an increasingly rare thing in Washington. Also, particularly my colleagues in this whole affair, some of whom are here today and some of whom are not: Jeff Hoffman, Dava Newman, and Annalisa Weigel, Larry Young at MIT, John Logsdon, our students, two of whom are here today Eph Lanford and Teasel Muir-Harmony who you met as you came in, there's Eph, Teasel's probably out there as well, who teaches as much as our guests and our own teaching does and whose excitement for the topic also energizes us all. And finally, someone who you've probably all interacted with leading up to this is Scott Uebelhart, who you'll hear from in a little bit. Scott's a MIT engineering Ph.D. who's both worked in the technical side at Draper Labs and has been sort of making a switch over to the policy analysis world and has been the organizational force behind both our SPS program in general and this particular forum and is also doing then—as you'll hear—his own work on the utilization of the Space Station and a number of other issues, none of which are easy topics. And I will add, and I can do this because I'm not Scott, that he's on the job market, so if you want someone who's got very very current knowledge of the space policy scene, Scott is a great person to look at.

Our goals today really are to create and continue a conversation, a conversation that's been ongoing around this important transition in U.S. human spaceflight since the publication of our white paper last fall and of course since the beginning of U.S. human spaceflight in some ways. Of course we never imagined this late into the spring that NASA would still be without an administrator and that delay in some sense renders this conversation more important because the window for input into the process is longer than we might have expected it will be, and I hope that the window does not close when a new administrator comes on board either, but there's clearly really a voice, an opportunity here for the voice of the community to be heard as evidence by the new review that's just been announced to be undertaken by OSTP, and I will add on the agenda, John Logsdon suggested and which is good for me because it's during his closing remarks period that maybe we would like to listen to the telecon that Norm Augustine is going to have at 11:30 and we're set up to be able to do that, to stream it via the web and hopefully it won't be too long and it will leave us a few minutes for more conversation and for some comments by John. 7:11

Let me add as well that this is the first forum like this that we've conducted but we'd be happy to do it elsewhere again in other venues. It's really an experiment, although not an experiment, I'm sure will have an interesting conversation, but if you or your organization has an interest in continuing it we may follow up with a conference at MIT at some point, it depends a little bit on what happens in the world. We'd be happy to help out with or organize something.

Of the panelists today, a few of them are colleagues from the SPS group who've worked on this white paper with us. Jeff Hoffman, Scott Uebelhart I mentioned, John Logsdon, and John Tylko. But others are not, are people who actually engaged us in the conversation in the wake of the publication of the white paper, particularly, in the first panel Dan Lester and Mark Craig, and others are general colleagues in space policy, like Scott Pace. Not everyone on these panels, as I said, worked on the white paper; not all of them agree with us. We're not here to promote any particular set agenda. Not even all of our co-authors who did work on our white paper agree. Sixteen people on the author list with fairly a diverse set of opinions to create a short policy document was no small challenge as I'm sure you'll appreciate.

The goal of the white paper was actually simple although it has complicated ramifications, that is to revisit the question of why do we send people into space. More precisely, what are the objectives of a large government funded program to send people into space, so we're not actually directly at the moment addressing the commercial spaceflight, commercial human spaceflight business, but it is clearly a player in the story we're going to tell. Many answers to this question have been given over the years, and we intended a little bit to filter them out into a set that are compelling, policy-relevant, and consisting with technology as it evolves. A few assumptions, which actually are not as well stated in the white paper as we would of liked: first of all, we're focusing on human spaceflight. There's a lot of work that's done on civil space policy or space policy overall, and we think sometimes that the enormity of the issues in a lot of those areas can dilute some of the focus on human spaceflight. We also are assuming that U.S. human spaceflight will continue, we're not looking at question or the issue should we have a human spaceflight program or the question perhaps should we have a separate study. We just concluded in the course of our work politically that we didn't foresee the program being outright cancelled. There are people in the community who are very worried about that. It's probably a legitimate worry and a legitimate topic of conversation, but not the way we're looking at it. We're really saying given that the U.S. has and will likely have human spaceflight program, what should it look like? What's the best way to think about it? We're also realistic about funding, and not making a case for an enormous, Apollo-like increase in funding, merely triple NASA's budget and everything will be fine, that's a very easy thing to say, doesn't have a lot of impact these days, and to quote one of the scientists we interviewed in the course of this process, we ought to be able to have a good space program for 17,18 billion dollars a year. Finally, we're seeing the issue in a global context. As you know, the U.S. human spaceflight was born in an era of international competition. Whether Americans still see us in that era of competition or not, the fact is many people in other countries do, and other countries are actively engaging in human spaceflight and actually Asif will talk a little bit about the global context, but elsewhere he makes the point that human spaceflight has always been a global endeavor between Germans and Russians and the United States, and the flow of ideas and people across borders has been part of the history from the beginning.

So let me begin with a little anecdote that will lead us into our framework. We interviewed Steve Squyres as part of our study, and he made a point which he said in public, and I'm sure you've heard. He said for all the success of the Mars Rovers, if I had a real geologist standing right next to them, I could've done ten times as much work in the amount, in one day as they do. And there's a variety of numbers he'll throw around for the ratio there, but no question that if a person was there we could do more with the rovers. And then he will say but I don't claim that kind of added capability would justify the cost of a human mission to Mars. And that comment leads us into a set of ideas about once a human is present in a given place or in an orbit, clearly there are lots of wonderful things that humans can and do do. But why are they there to begin with? Again, following

on Squyres' comment, if we were all transported to a conference room on the surface of Mars, and we knew what we were looking for and we had the adequate protection, no question we would do all kinds of amazing things. But what does it take nationally, culturally, politically, financially to get there? And that's sort of the question that led us to this, what we're calling a framework, it's really a basic just set of ideas, actually maybe we can zip ahead a little bit. What we're calling our framework. And that's what we call primary objectives of human spaceflight are those that only are achievable through direct human presence, whose benefits exceed the opportunity cost and are worthy of the risk to human life that we all know comes with human spaceflight. And then by secondary objectives we talk about benefits from human presence that what you would obviously have if you had a human there but aren't themselves the purpose for justifying the risk or cause. And we very much don't mean to imply that the secondary objectives are unimportant or that they haven't contributed major things in the course of this history or in the future but simply there are not in and of themselves the source of particularly the political support for the programs. I should mention by the way that this idea maps pretty well onto what Mike Griffin talks about as real reasons and acceptable reasons for human spaceflight, the real reasons being the things that motivate the people who are involved to dedicate their lives to this endeavor, the acceptable reasons being the reasons that are presented to Congress and possibly the public for why this is accomplished, but we like a different framing of it, not least because we believe the real reasons should be the acceptable reasons, and that there's been some of the problems are attributable to this disconnect between what's real and what's acceptable.

One primary objective, a major primary objective as we see it is exploration. And we try to use that word with at least a little precision, which is not usually the way that many people do it. Dan Lester will point out the multi-valent uses of the word exploration, and we're not, none of us have any hope of finding a stable definition for this term. One of the richness of the term is that it means so many different things, but for us, we talk about it as the expansion of human experience, putting new people, putting people into new situations and expanding the realm of what it means to be human. I use the famous picture of Buzz Aldrin because to so many people this image is the icon of Apollo, and it is a human on the Moon as opposed to a scientific sample or other types of, many other images from Apollo. We actually reject the idea that exploration is written into our DNA. We don't find that a useful nor empirically supportable conclusion. Historically and in social science we don't find compelling need to explore. Many cultures have succeeded without exploration. Some cultures have succeeded with it. Some cultures have failed with exploration, and at a particular time, at a particular place sometimes groups of people, nations choose to explore and other times they don't. If this nation were to choose to stop exploring, we would stop exploring, and we'd rather find this idea of human experience, which is a complicated one because as most people pointed out in response to the white paper, it's a little bit circular in the sense of defining human experience, defining exploration as something that requires human presence and then saying human presence is one of the justifications for exploration. But it's also complicated by the fact that remote experience, remote presence, the very nature of what it means to have human experience changes with changes in technology, and that's one of the things we're grappling with.

Other primary objectives, which will be mentioned by the panelists include obviously national pride, international prestige, global leadership, and again very much in a global context and Asif will say a little about comparatively what other nations have seen as primary objectives for human spaceflight, and they're not all that different.

Let me say a little bit more then about the human experience piece of it. In the course of my study of Apollo and now about five years teaching a course on the topic to graduate students at MIT, it's been fascinating how much the human experience of the program forty years out is, sort of rises to the top as one of the major products or impacts of the program. If you've seen the recent excellent film *In the Shadow of the Moon*, which is a film that has wonderful visual footage, very little actually new historical information that wasn't in the sources otherwise, but what's relatively new about it is that it emphasizes the astronauts' own experiences and it pretty much explicitly says the major impact of Apollo was from the experiences of these twelve men. I have a funny story about this in that last week Dave Scott, the commander of Apollo 15, came to MIT to visit, to speak to our class and to meet with students, and before class we had a lunch with a bunch of the graduate students and one of my students brought his eight-year-old son, who was—as we all were—thrilled to have this Moonwalker come visit and people from our group were asking the usual very sophisticated questions about technical aspects of the program and new issues in space policy and so on and so forth, and finally Dave Scott said to the eight-year-old boy, Jeff, don't you have a question you'd like to ask. He was very shy, very intimidated, and his dad said, come on, driving here in the car you had lots of questions, you know. Why don't you ask a question? And little eight-year-old Jeff said what was it like to walk on the Moon? And everyone around the table spontaneously laughed. And the poor kid was horrified for a moment, but then Scott said we're only laughing because that's the question we all really want to ask but everyone was afraid to ask. And as you know, that's probably the most common question that astronauts are asked whether they were on the Moon or in space and is another indication of the importance of the human experience as a product of human spaceflight. They're simply twelve and then nine people who walked on the Moon, who've done what no human has ever done before. They changed the definition of what it means to be human. Actually, we don't get a lot of pushback on this idea, I think Jeff Hoffman believes it's reasonable, I think he'll say a little bit about that and people seem to find it, to basically agree. But it's actually a radical idea. If we really believe in these primary objectives or that human experience is a primary product of human spaceflight, what kind of a space program should we have? And whether it's human experience or the other primary objectives, a lot of our goal today is to talk about are we planning and executing human spaceflight programs that really reflect the primary objectives or what Griffin would call the real reasons. If we believe in human experience as a core principle of human spaceflight, for example, we might do a better job of incorporating remote and virtual experience into both the remote probes and the human spaceflight projects. We might plan our human missions for example with a better mix of telerobotics and human presence so scientists and/or the public can experience the missions in parallel with human participants. We might even train or select our astronauts with more emphasis on their ability to communicate their experiences since that's a great of what they do when they return.

So what we hope to do then, this is but one example, is explore the policy implications of this framework. If we accept certain reasons as primary and certain reasons as secondary, which I don't expect we'll all agree on which ones are which, but there's some broad agreement about a lot of them. What are the policy implications? What are the implications for an architecture? Even if we disagree on which are primary and which are secondary, at least then you can formulate policy options based on allowing decision makers actually, and you really want political leadership to say these are what we consider primary objectives and we want an architecture that reflects those primary objectives. So the second panel really explores that. Next slide please. So this is a rough outline of how, of what I've just said really. On the left we have what we're calling our framework, again it's really just a pair of ideas. Welcome to Scott Pace who's our co-sponsor in this event from

George Washington, and on the left we have the ideas, the primary/secondary objectives, the middle column, and that we're relatively secure in. We really believe in that conceptual framing. The middle column are the objectives which for our purposes we've divided. I know that not all of our panelists agree on which falls into primary and which falls into secondary, so we'll have some conversation on that. And then on the right are the questions, many of them about what are the policy implications of the ideas, and where do we go from here, and much more speculative from our point of view and in some cases particularly surround things like the station very difficult to fit into the framework. And next slide please. I've just sort of circled the area where we see ourselves as having the conversation today in that interstitial area between the second and the third column.

Let me give you one example of why this matters. Some have said that the human spaceflight policy was set by the Bush vision in 2004, Constellation architecture reflects that policy and there's nothing more to talk about. We disagree with that point of view. In fact there are so many places, if you look for example at the Altair lander design studies where the tradeoffs being made are really tradeoffs that are policy tradeoffs. Do you organize a series of sortie missions to different parts of the Moon for your global access or do you go from an outpost point of view and do a series of either hoppers or mission from an outpost? When you look at the architecture and the set of trades around a question like that, it comes down to what kind of science are you trying to accomplish? What are the goals of the mission? That's not a decision that you can make in a policy vacuum. Similarly with the global access requirement. The ESAS study sort of lays out global access as a requirement, but how would the lunar scientific community weight different latitudes in different ways versus different parts of the versus longer stays in other latitudes. Right now that's not being incorporated into the trades that are being made in the Altair's design. A surprising number of technical decisions are being made on simply the basis of bigger than Apollo, better than Apollo, larger than Apollo. Understandable why those are being made, but that's, in our opinion, not of the best basis for national policy. It's also really not how we research or teach technology and policy at MIT. In fact, one of the core principles of how we teach is that the policy considerations are actually reflected right down into the very details of the design and vice versa. The constraints of the design constrain the options available to policy makers. And so our goal today is not to discuss the details of the architecture nor the trades between Constellation and the EELV etc, etc, but we do think that there's a responsibility, and hopefully this new study that's being commissioned by OSTP will open this question up for the agency to provide a set of options to the policy makers, a series, I think of them as axes for trade-offs allowing the political leadership to say, essentially these are our priorities: fifty-percent national pride, thirty-percent science, twenty-percent international collaboration, that's an over simplified way to put it, but then that sort of mix will put you in a certain place in an architecture-cost-schedule-trade space.

So that's all I'm going to say by way of introduction, and our panelists backgrounds are detailed in the program, so I won't repeat that except to say a little bit about how each one came to be here. Dan Lester and Mark Craig, as I mentioned, are both people who were not part of our study, but engaged us both critically and productively in the weeks and months since then and we're very happy that they're here to join and many of the things in the study speak to ideas that they've been working on or thinking about for a long time. Jeff Hoffman, as I mentioned, has been part of our study since his years at NASA and as a professor at MIT now and has been a tremendous contributor as far as the only one of us who's actually been there from the point of view of human spaceflight. And then Asif Siddiqi whose day-job is as professor of the history of spaceflight at Fordham University, and I'm sure you're familiar with his definitive book on the Soviet lunar program, but has been more

recently working on a history of the Indian space program and we brought him up to MIT to give him broad leeway to work on his book and get his research done, but then we sort of dragged him in as a collaborator on all this and has really helped us a great deal with the global perspective. So I'm going to turn it over to the panelists. We've asked them to take about ten minutes each to share their thoughts and then we'll leave plenty of time for questions. Thank you.

Panel 1: Objectives for human spaceflight

Dr. Dan Lester, University of Texas, Austin

It's really a pleasure to be here. A lot of hard work has gone into making this happen. I have ten minutes where I want to try to get something across. And I wanted to challenge you in the context of human spaceflight and the questions that we're here to talk about, and I want to challenge you with a word and the word—David had mentioned before—the word is exploration. You know, our whole spaceflight enterprise is predicated on that word. And I think it's very important that we give some thought to what that word actually means. In order to do that I'm going to start out by taking off in the country side, and let's pay our respects to an explorer who braved great danger flying rockets, going off into the unknown. I know you're all wondering who that explorer was, let's look at the epitaph on that stone. Robert Evel Kineval. Explorer, Motorcyclist, and Daredevil. Yes, Evel Kineval saw himself as an explorer. He wrote that epitaph, and in his various work with the press, with his adoring fans, he used that term all the time. And you look and you say, I don't know if I think Evel Kineval was an explorer, but okay, you can believe that. Let's go on. A year and a half after the vision for space exploration came out Bob Kirschner, president of the American Astronomical Society, issued a statement, from the society, on the role of science in the vision for space exploration, and the problem was the role of science wasn't all that conspicuous, a year and a half later it looked like science had been put in the backseat, and he coined the phrase exploration without science in tourism. And I like tourism, but I think he meant that critically. And you look at, and the science community applauded that and as a scientist I say, yeah, boy that's exactly right, but you know, if you think about it, I know lots of explorers from our history who were not scientists, who did not do science. Christopher Columbus, Vasco da Gama, Kit Carson, Simon Fraser, these are people we respect as explorers, and they didn't do science. So there's something wrong with this. Here's a nice quote from Mike Foul. Michael has actually been in orbit, I think longer than anybody else, I think he's put in about 370 days in low earth orbit. He's been up there a lot on many missions.—Than other Americans, good point, right. And he has this really interesting quote. Let me read it to you.

I'm certainly exploring when I look out the window and I look down at the earth and I see the Himalayas go by and I see Tierra Del Fuego go by and I see Spain, Britain, and the United States.

And we say, well, wait a minute, is that exploring, sitting there looking out the window? He said it was. Look, the point of all this. Oh, and I'll say that it's obviously personal exploration, and we all know about personal exploration where you can take out your wallet and checkbook and write a check and you can be an explorer too, okay, alright. But the point of all this is I think captured in this slide here, that exploration, that word means very different things to different people. And I can look out in the audience and point to anybody. Nobody out here thinks they don't know what exploration is, okay. But I'm not sure if we all agree. There's this wonderful quote from Chief Justice Potter Stewart in the famous obscenity case decided whether a certain movie, *Les Amants*, is actually pornographic and should be banned. He and court decided that it wasn't. And in his concurrence he said “hard core pornography is really hard to define, but I know it when I see it.” And I think to a great extent when we look at exploration, we all know it when we see it, even though we have a hard time actually defining what it is.

Now you say, eh, Dan, it's just semantics, okay. It's just a word. You can take that word and use it any way we want. I think David said it's nice to have flexible words, but there's a problem with that, and the

problem is we use it a lot. We have a vision for it. NASA has a directorate for it. They have an enterprise devoted to it. Here is the FY09 budget proposal, I should have done this for the FY10 budget proposal that just came out, that word comes up about a thousand times in that document. That document is based on that word. Let's look at the last NASA strategic plan from a couple of years ago. I love these word clouds, where of course the size of the word is proportional to how much it's used and so you get rid of words like "a" and "the" and in this case I think "NASA" and "agency", and that's what's left! Look at exploration. Exploration is just a major part of what NASA sees itself a doing.

I do a lot of work in the schools. I've probably talked to a couple of thousand fifth graders over last couple of years, and after we do the things the teachers want me to do, which is talking about the scale size of the Earth and the Moon and the solar system and orbits and stuff like that, I take them on a trip to Mars, and these fifth graders love it. And we go with Spirit and Opportunity to Mars and spend a half hour talking about that, showing movies and I always like to ask this question of them, putting up these pictures. Who's the explorer here? Is it Spirit or Opportunity on the left? Or is it these people, a sample of the many people that made Spirit and Opportunity happen, on the right? But where's the explorer? Point to the explorer. And you know, when I first started to do this, I thought figured, you know, the WALL·E generation, they're going to point to the picture on the left, because there's the explorer over there. They don't. They don't miss a beat. The explorers here are those people on the right who go home every night. Actually they probably go home every Martian night, but that's okay. And so there are people who wonder, is this exploration? When we're not there? Well in eight years, you're going to have a whole lot of voters who say you can have exploration when you're not there a whole lot.

So the recipe for exploration. What are the ingredients for exploration? Gosh, you know I just wrote down a whole bunch of words. Does it involve being first at something? Maybe. Bravery, discovery, science, risk, risk is important, suspense, frontiers, new places, fear, hadn't thought of that, someone suggested that to me, challenges, breakthroughs, searches, you know, you say, yeah! All that stuff. But then again, if you look back at our historical precedence, you can find historical precedence in which these words don't apply. Here are some quotes from various important papers that have come out on space policy: "The purpose of sustained human exploration is to go to Mars and beyond." The purpose is to go. "Exploration is the establishment and the pushing back of a frontier." Those words actually came from the Aldridge Commission Report. This next one you should recognize: "Exploration is the expansion of human experience." Of course that came from the SPI white paper. And then you can find things like "exploration is the travel for the purpose of discovery." They're all wonderful, solid, great definitions, and they're all different. The definition of exploration is not the issue here. That's not what I'm trying to do. But we have strategic plans that are based on doing exploration, which is a little awkward when we don't agree what it is. And if we don't agree on what it is, how do we know when we've succeeded in doing it? I think as a national enterprise, if we can't get any consensus on it, at least we have to have some respect for the fact that this is a very flexible word.

Okay, my last slide. I'd like to suggest that there is a need for some national dialogue about the value and purpose of exploration. It's a word, it's a flexible word. Is a flexible word for something you're planning strategically a good thing? Maybe. What does human spaceflight bring to it? We'll hear a lot about that today. Historical precedents are very important. When we talk about explorer, what I feel is being an explorer is based on what we see in looking back in our history. You have to ask the question, is exploration what it used to be? As I say many times, if Thomas Jefferson had Earth resources satellites, Lewis and Clark may never have

gone. Historians talk about the frontier myth. This is the romanticization of our history in which, of course, all of our fathers, grandfathers, and great-great grandfathers were all rugged men sitting on horseback in jeans with a gun at our side, braving the frontier. And in fact, that's not true. We come from a very agrarian society, there's not a lot of frontier in our background. It's not that the myth is wrong, it's not a myth because it's wrong, it's a myth because it's just a story that we use. Is there an exploration myth that we need to be conscious of? So finally, look, I challenge you in the course of today, tomorrow, whenever to explain to your friends, your families, your colleagues, to the nation what exploration is. And don't walk away from that question, don't be so fast to use exploration as a shorthand for something that you really don't want to talk about. Thanks.

Dr. Jeffery Hoffman, MIT Department of Aeronautics and Astronautics

I don't have any slides, but I'm going to start out by giving my own cut at the way I look at exploration. At least the exploration of the universe because, actually I think that exploration goes much beyond that. I mean, we have people who are explorers in all aspects of human experience. In art, in music, I mean, Picasso was an explorer. He expanded human experience. Arnold Schulenburg was an explorer. I'm going to leave that to the side. Exploring the universe. I started life as an astronomer, and I look at astronomy as exploration. It is not active exploration; we can't actually go out and interact with stars and galaxies, but when we look at the incredible difference between our concept of the universe today and what it was when I was a kid fifty years ago, how can we say that astronomy is not exploration? But it is passive. We basically, we have to deal with the photons that arrive here, we can't go and physically interact with the things that we study. And then, in a very, very much more restricted volume of the universe, and I don't want to get into cosmological questions, but when you look at the volume that can be explored by the Hubble Space Telescope and compare that to the volume of our solar system that we can explore with our robotic explorers, it's a factor of, ten to the thirtieth, so you know, unless we get some sort of warp drive like in Star Trek, the unbelievably vast majority of the universe is going to continue to be explored by astronomers, and by no other means. But where we can actually physically interact with the environment that we're trying to explore, I think everybody would agree, that the qualitative as well as quantitative exploration what we can achieve increases tremendously. And I think that when you look sometimes at debates between human and robotic exploration, I would say it strikes me as being strange that we don't have that same argument between telescopic and robotic exploration. You know, Steve Squyres, as you said Dave, he said, well humans could do a lot more than robots on the surface of Mars, but he wasn't sure he could justify the cost. Well frankly, we could have made a choice just to look at the surface of other planets with telescopes. But we know that sending robotic explorers to the surface of these planets allows us to accomplish a lot more, but it's a lot more expensive. But somehow we don't get into the same type of almost theological debate about telescope versus robotic exploration that we do when we talk about humans and robots.

I've spent a large part of my professional life involved with human spaceflight, and yet I'm a great fan of robotic exploration. And what I'd like to do in the short amount of time that I have is to talk a little bit about a vision for the future of human and robotic exploration, and in particular, the opportunities to get humans and

robots working together. The only place where this has ever happened has been, so far, on the Space Shuttle and the Space Station, where, in fact, we've had a very, very successful synergy between human and robotic systems, and I'm referring of course to the robotic manipulator systems on the Space Shuttle and the Station. When we went up and fixed the Hubble Space Telescope, we couldn't have done that job without the robotic arm, but as we found out when we started looking at the possibilities for a purely robotic mission to Hubble, our robotic technology is not up to the task of being able to accomplish what humans are currently able to accomplish. So working together, human and robotic systems, we were able to do think things that neither could do on their own. Now, I'll start going back to a point that David made, sort of stole my thunder about what's it like on the Moon, but I'll just repeat one more time that there's no question, the first question that I always get asked when people find out that I've been an astronaut, I've been in space, is just precisely that: what's it like in space? And that is a fundamental difference. You cannot ask that question of a robot. Robots do great jobs at measuring magnetic fields, charged particle density, the solar wind, I mean, all the sorts of scientific things we want to know about space, they do a much better job than I could ever do. But they can't answer that fundamental question because what people are really asking is not what's the physical environment of space. They want to know what is the human experience of being in space, and so there is that fundamental desire that humans have to experience things that they haven't experienced before. And when we talk about the space program satisfying the stakeholders' needs and realize that the public is one of our most important stakeholders, I think it's very important to satisfy that need. Now it is true that we have now developed robotic systems which extend human capability, and I think that the development of much better virtual reality tools to communicate both the experiences that our robotic explorers have and also that our human explorers have is extremely important. Let me make a suggestion that when we go back to the Moon, that's going to be an ideal opportunity to look at the interaction of human and robotic systems on a level which we have not been able to do until now. Certainly on a much more sophisticated level than we do on the station or on the shuttle. Let's remember that particularly in the early years of going back to the Moon, we don't know exactly what's going to happen, but it's almost certain that the first few years are going to be primarily rather short sortie missions, and I'd like to suggest that we could expand tremendously the exploration potential of those missions if we devoted a certain fraction of the resources we take to the Moon and a certain fraction of the astronauts' time on the Moon to setting up a robotic exploration infrastructure. That way, when the humans come back, the robots can stay and continue the process of exploration, and in terms of synergy, you know, let's think of probably, the most difficult and dangerous parts of a robotic mission are the initial landing, the deployment of the robot to the surface from the platform that they land on, the initial activation and checkout. If you have humans present on spot, those activities can be performed with far less risk, and probably that means that systems can be designed less expensively, and I think that that's extremely important, because, frankly, we can't afford the sort of robotic exploration that we're seeing with Mars Science Lander. I mean, if it costs upwards of a billion dollars every time we want to build a new robotic explorer and send it to the Moon, it's not going to happen. So that's a big challenge for the robotic exploration community. So the first aspect here is that we can set up a robotic infrastructure. Then, of course those robots can then be tele-operated or autonomously operated, whatever makes sense from the Earth. Then if humans should happen to return to the same area where they made their first visit, you have another opportunity for synergy because, at this point, humans can actually repair and reconfigure the robots in the way that we have serviced Hubble over these years and vastly extended the value of Hubble as an astronomical tool. And of course if we ever do get to a point of building a lunar base, we don't know how that's going to work out, but if we do, then it would also certainly

make sense that when humans complete a short sortie mission near the base they can set up the robotic infrastructure that will actually help the base construction while they're gone. So there's all sorts of new things that we can try to do with robots, taking advantage of the presence of humans to extend the amount of exploration, and I find, just finishing up, we've been working in our space architecture group at MIT on looking at some aspects of lunar architecture, and one of the things we've been working with NASA on is to set up figures of merit to judge the efficacy of certain types of architectures. And the problem that I find is the figures of merit always seem to refer to what the humans can accomplish on the Moon. What I would like to see is figures of merit which measure the total exploration that we can accomplish, humans plus whatever robotic systems we can set up while we're there. So in a word, that's my hope that when we finally develop the lunar exploration architecture, we will have a rational mixture of both human and robotic resources so that we can really explore what we can do working together, and in the end, I think we are going to be able to get a lot more exploration than either humans or robots could accomplish on their own.

Mark Craig, SAIC NASA Account Manager

I do want to thank MIT for the clear thinking that put this paper together because I do believe that it's critically important, and also for convening us in a group to continue the discussion about how we perfect this and how we make it happen. Thank you.

What I'd like to do is spend a few minutes talking about the significance of this white paper. I do think that it is very significant in ways that most of my community has missed, in my opinion, and then talk about some suggested improvements. Significance. I think one of the very first things that this framework does and that our culture and community has a very hard time with, it really starts with first principles. We love destinations. We love vehicles. We love devices. We love technologies. And often, that's where our strategic discussions start. First principles. It is very important in strategic discussions to understand what first principles are, to articulate them, agree on them, and then move forward from there by flowing them down. That this paper does. It ignores destinations and vehicles, and in doing that, it lays out a set of objectives, as Dave said, and a set of key considerations, which I think are key to begin the process of figuring out a future for NASA human spaceflight. In these comments, one of the things that it does that I think personally is critically important, it focuses on benefits and benefit costs, opportunity costs, as Dave said, but what makes this relevant? What are the real benefits of these activities? And a number of these comments are going to be based on that. Second thing of significance that it does: it mandates that—what it calls—concrete plans be included in the policy to ensure a flow down of objectives into implementing action. These are things that are easy to talk about. They're probably easier to put in policy, but unless they are true plans about how these things are flowed down, the implementing actions, they're not real. You gave an example, Dave, of Altair. One could come up with many, many others. Human spaceflight over the last many years, I think, has had a real challenge, and history of a disconnect between the policy and the detailed engineering implementation and planning, and by having concrete plans, we have a chance to get around that. Benefits have to shape what we do, we just don't claim it. A lot's been said about defining exploration. I think that is critically important, and to Dan's point, it is an ambiguous term, and there's a lot of power in that ambiguity. But some of the concepts that the definition in

this paper bring forward are critically important. Human experience has been talked about, and that is just key. Both Dave and Jeff have talked about that, so I won't. It's not only the experience of the astronaut and the human being that is involved in the actual act—or what's seen as the act of exploration—but it's all the others that could be involved, remotely. So we have to always see that as *writ large* for as many people as we can cram into it. Second thing that's important about this: it talks about exploration in terms of new situations and environments. One of the things I think that has hobbled our community over time is that we tend to think of exploration as only new places, and that's a trap. I mean, at some point, you run out of technically achievable destinations. So you have to understand exploration as *writ much larger* than just places, and defining it this way I think is very useful in doing that, and is very useful in shaping activity to it. And finally, I think there's significance in that this definition of exploration highlights how little we've really explored the weightless environment in Earth orbit, for the benefit of humankind. We've learned how to get there, we've certainly learned how to work there, on the Space Station, but now how do we use this, you know one hundred fifty miles up weight disappears. How have we begun to understand what that means to terrestrial processes: chemical, biological, physical, etc? These are four points I'd bring forward for your considerations as to the significance of this white paper. And they are actionable items in terms of their significance.

Suggested improvements: as you might guess from my comments, I think in talking about concrete plans, they're mentioned for ISS utilization and Moon-Mars strategy, I think it's critical if this is to really achieve its potential that a concrete plan be specified for how the policy is flowed down, to actually deliver benefit, not just assert it, not just talk about it, but actually shape our efforts to deliver it. If we don't have that, it's not going to happen. In our past, we tend to depend on serendipity, kind of do what the engineers and scientists want, and well it will be valuable, it will be benefit, or we do occasionally get real policy guidance, like the international guidance we've gotten, but we need a much stronger framework to do that. There is technology an approach that tells us how to do that. Companies live and die by their ability to understand their value, their benefit, and then shape their efforts to deliver that. Value propositions, value chains, branding, the research that goes into determining value. All those technologies exist. They're there for us to make use of. We ought to as we put together these concrete plans to flow our objectives into benefit. In that same vein, I think even with concrete plans, it's not enough. I don't know what to call it, but I think the human spaceflight community needs, I call it, an accountability framework, an external accountability framework. The science community has that in the National Academy. There are other models one could devise, but if we're really serious, which we need to be, about flowing these objectives, these benefit objectives into action, we need an external accountability framework to make that happen, help assure that it's happening, and happening properly. Changing science to knowledge. Science is objective. I would contend it's broader than that. There's certainly a scientific knowledge we get from exploration, but I think there's also medical knowledge, there's engineering knowledge, there's exploration knowledge itself. So I would recommend we consider changing science to a broader and more complete definition of what the benefit is, which is knowledge for human spaceflight.

And finally, life science research. In terms of relevance and benefit, and this is a personal view, if there's anything we can do in weightlessness that helps advance human life science research for the inhabitants of this planet that is relevant, that is seen as relevant, that has power to it, it is human life science research. We have an aging population. We are daily confronted with the challenges in this domain that I very firmly believe human spaceflight can help with. Not necessarily using humans as test subjects, but using humans to do the

research in a weightless environment. This is not, we tend to view it and now we really view it as, human life science research for our own purposes. That puts us in rationale penalty box I'll call it. Here we have this tremendous capability, potential capability, this tremendous environment of weightlessness to do human life science research. We certainly need to do that research for humans to go out further in exploration, but we need to do that research much more broadly to benefit humankind and not get locked into this rationale penalty box of just doing it for ourselves when anybody can say we can improve delivery of medical products and services, everyone cares about that, and then only do it for ourselves is a problem, and is seen as a problem as shown in this cartoon.

One last thing I would say, our culture tends to view a lot of what we're talking about here, well it's just a communication problem. We just need to communicate better. We just need to do what we want and tell people how wonderful it is. This is not a communication problem. We kid ourselves when we think it is. Communication is key in this to help people understand what's going on, and it does in itself—as it did in Apollo—deliver some value, but as we limit it to just a communication problem, and do not shape what we do to actually deliver benefit, to be relevant, we are missing a tremendous opportunity. So things about communication are in my mind kind of a red flag. Well, that just an easy answer when it's not really the answer at all.

Where could this end up? I guess we have the opportunity here with the framework that has been laid out, by really focusing on relevance, by really focusing on benefit, not just talking about, we really have an opportunity here to develop, to elevate the debate about human space exploration from not the should we do it, which is often how it's framed today, but how much should we do. We have an opportunity here if we really focus on relevance and benefit by shaping what we do to weave space exploration into the fabric of society. It's not now today. It could be. We also, by focusing on benefit and relevance, and really delivering them through deliberate effort have an opportunity, well I think of it as really building a psychological highway into space. People really, people *writ large* understand that space is a part of our future, it's exciting, and we as humankind is moving into space. That's a psychological highway. We need to think of it that way, and delivery of real benefit and value, not just asserting it, but really delivering it is a key way to start down that path. So again, I thank you, Dave, for your efforts here and your team's. I think it's a real service to our community. And now I think the real challenge is to make it happen. That's all. Thanks.

Professor Asif Siddiqi, Fordham University

What I want to talk about is a little bit different I guess. It will be focused on the international context. A central question for me was really given the kind of framework outline by MIT, can we discern the rationales and objectives of other nations engaged in human spaceflight? And my goal is really to look at these other nationals and perhaps to help us put into context the rationales and goals of the United States. David outlined the primary objectives such as exploration, expansion of the human experience, also national pride, prestige, etc., As I'm going to go through a couple of examples, I want to talk about these particular primary objectives. What I want to do is just because of the time limitations I'm really quickly go through the human spaceflight

programs of Russia, China, and India and see if there's any kind of common threads, any different ideas that come up in terms of justifying and rationalizing human spaceflight in those other national contexts. I'm not necessarily going to talk too much about the operations and status of their programs unless they directly bear on some of the examples I give.

So Russia, China, and India. Let's start with Russia. Russia has obviously one of the most I guess mature human spaceflight programs. It's deeply involved in ISS, and recently they just announced a proposal to replace the Soyuz. Perhaps this will happen. If you look at the recent policy statements from the Russian government, particularly one issued last year on future directions of the Russian space program, which include everything, not just human spaceflight, I guess they list some of the rationales of their space program to about 2020. And from my reading of this, from my reading of these, of this particular document and other similar ones, you see that there's kind of a set of common threads running through it. One is obviously prestige. Prestige is a big driving force of their program. But it's interesting how prestige works in the Russian context. I would argue that the burden of history is actually a very strong driving point of their current program. What do I mean by that? There's a sense that Russia and the Soviet Union had a very robust and active and very visible space program during the Cold War. They're recovering from a big shock in the 1990s. And this burden of history in a sense infuses much of their rhetoric with once we were great and we can't lose this capability. And you see this in particularly in the sort of ubiquitous celebrations and anniversaries constantly in Russia about particular historical moments. So pride, pride in their program, which is definitely based on historical events is, what is what I would argue, a prime driving force of their current program. In fact, this document says, and I quote, one of the goals of the space program is to, quote, preserve the status of the Russian Federation as a leading spacefaring power. Preserve, which means preserve something that they believe they had once. Other issues driving the program are Russian commitments to international partnerships, and this is also spelled out in many documents. If you talk to people on the ground, they're also very much invested in this idea. Russia has pretty much fulfilled its commitments to ISS despite funding shortfalls. Putin himself, who is now the Prime Minister, one could argue has much more power, in a statement last fall, said that Russia would continue to be, quote, a reliable partner in international cooperation. So international cooperation and partnerships, I would argue, also drives their human spaceflight project. And finally, a claim for independence in space operations. They would like to have an independent space program, a human spaceflight program. Now they also list these documents, policy documents, a host of what we would call secondary objectives, like science, economic development, technological development, that play into the rationales for human spaceflight. And official documents list these rationales, but it's noteworthy that the Russia government has been reluctant to commit to any significant expansion of their human spaceflight program despite the claims of many space officials that there are tangible economic benefits to human spaceflight. In fact the government investment, the government investment key unmanned systems such as navigation systems have been persistent priorities of the government as opposed to overambitious human spaceflight programs such as, you know, lunar missions, and so on and so forth.

So, moving onto China. Obviously a very interesting case. What are the rationales, priorities driving their human spaceflight program? Obviously an emerging human spaceflight power. In 2003 they became the third nation to acquire an independent capability to launch humans into orbit. Again, if you look at some of the official statements coming out of the government, you know, I've summarized a few, they list a couple of rationales for their program: science, economic benefits, national security, and national prestige. In that order

particularly. If you sort of put the aggregate of official statements together, you do sort of notice that although science and economic benefits are particularly at the top, prestige really sort of hovers over other rationales as a very primary objective of their program, to the human spaceflight program. The Shenzhou missions since 2003 have brought the Chinese government an explosion of enthusiastic, nationalistic feelings at home, as well as what some would call soft power gains at least in the region if not further beyond, the region being in Asia. But if you break it down a little bit prestige works in, there are sort of local flavors to prestige. There's no one all sort of prestige concept that works globally. For example you see in some of the statements the human spaceflight program is in some ways a vehicle for encountering an image of China that is about producing cheap, low tech goods for the rest of the world. Here we are, we can put a human into space, this kind of translates into a symbol of technological advantage, which, some would argue brings real economic dividends, and would perhaps translate into greater political influence. China also talks about international cooperation just like the Russians as a very important goal in terms of space exploration. Now in the human spaceflight context, they haven't obviously, their Shenzhou spacecraft was obviously derived from a Russian technology, but they don't have any sort of major cooperative programs. But they have expressed interest in joining ISS, and there are a series of statements from the officials suggesting that they would be very much interested in international cooperation, at least a limited form. All this talk about exploration, if you look at the Russian statements, exploration really doesn't factor into it at all. There could be a long discussion about why, there could be a long set of cultural, historical reasons why exploration wasn't really that central to the Russian vision, partly because the Soviet model was essentially about remodeling and recreating kind of the domestic Soviet new communist man. It was really internally focused, where as I think. I think the kind of frontier myth that is prevalent in the United States isn't, we don't really see it in the Russian cultural context. China talks a little bit about exploration, but again not in the way that NASA does, in very sort of moderated way.

My last example is India. Which is perhaps the most interesting case right now partly because the Indian space program is at a very crucial transitional phase. It is about to be, if what they say is going to happen, about to be the fourth nation to launch humans into space very soon. So to understand Indian rationales, you really have to go back to the roots of the program in the 1960s, when the program was founded by a kind of a technocrat, Vikram Sarabhai, who felt that the Indian space program should be entirely focused on domestic needs: alleviation of poverty, national development, etc. He didn't want to conform to the Cold War model of competition and high profile missions, etc. And he focused particularly on a space program that would have very much kind of a domestic development flavored missions, but also of self reliance. The question of why does India need a space program when it's so poor, when it has so much poverty, he sort of inverted that question and suggested that India needs a space program precisely because it's poor to alleviate those conditions. Through the 80s and the 90s this model was actually central to the program, but something dramatically changed I'd say about six, seven years ago. It was almost like a light switch went off, and India announced two programs that really deviated from this domestic development model. One was a deep space mission, a lunar probe mission, and the second was a human spaceflight program. Well why did this happen? There's some structural reasons. High growth rate in the Indian economy, they have the money. Vast and a fairly mature infrastructure and the program. Launch vehicles, ground systems, etc. And a large trail of highly, a large school of highly trained man power. But really the one sort of factor looming over all of this is prestige. And so you have a kind of a national program that has now the capability to move beyond the old model, and you also have a regional power, China, who is about to move into a very expansive space program. And it's not a coincidence that in early 2003 the chairman of the Indian Space Research Organization, Kasturirangan,

emphatically stated that India would never have a human spaceflight program in an interview. And this changed obviously very quickly, within a couple of years, right after the two Shenzhou missions, and in 2007 the Indian government committed to initial funding for a human spaceflight program for an initial human spaceflight capability in about 2014/2015, and I think a couple of months ago the high level commission in the government finally approved the project. Whether it's going to happen on time is questionable. From my conversations with various officials, I sense that it will happen. What are the official rationales for the Indian space program? Well there's a kind of, a very similar to the Chinese model, there's a need for independence in a whole spectrum of space activities. Economic benefits and so and so forth. There's a host of secondary objectives that they sort of talk about. The prestige issue doesn't really infuse much of the rhetoric of official spokespersons. But you do see it in terms of people, especially former officials of the space program who've I talked to, really insist that this is all about prestige. And a number of ISRO officials have talked about this idea off the record. The interesting thing that, their notion is that human spaceflight is a marker of a modern, regional superpower and perhaps a global superpower. Human spaceflight is a marker of modernity to many in India and also in China. And it's interesting I think, what I like to do is sort of end with this sort of last thought, which is that the emerging human spaceflight powers such as China and India are in essence using some of the model and the rhetoric of the 1960s Cold War space-race that we have essentially abandoned. And so they're recreating and talking in terms of going places that we've already been, but in a sort of new, reinvented way using some of the same rhetoric of competition and having particular deadlines to meet, and so on and so forth. And so it's interesting that a model that we've left behind is being used in an international context, and in the Asian context particularly, as kind of a new space-race. So those are just some of my comments.

Questions

Question: Harley Thronson, GSFC

In contrasting the three, the three countries that you just briefly discussed, there are a number of other advanced countries, large economies which seem to have no interest in human spaceflight, or at least very cool, lukewarm, Japan, much of Eastern Europe has not been very enthusiastic, the exception might be Germany, so there's probably as many advanced economies that aren't very interested in human spaceflight as they are that are. So what would you make of that? What is in the nature of these other countries to make them uninterested in human spaceflight versus.

Professor Asif Siddiqi

Well a couple of points, just some quick points, it's not ESA and Japan don't have human spaceflight programs, they do have them [independent], independent. So with that caveat, I think that well, my sense is that those programs, those space programs are relatively mature programs, they've have these you know, sort of, if you look at the overall spectrum of their space programs, they started in the sixties, they're quite mature and they have, I think that in some sense they're also very developed nations, and in some sense that notion is—especially for nations like China and India, which are sort of developing and upcoming nations—I see that as a difference, a primary difference in some sense, because if you have a very developed economy, developed nation, mature space programs, you're not necessarily invested in showing the rest of the world what you have to do to become developed. China and India have a lot more to prove in that sense, and that's my general feeling that ESA and Japan have a lot less to prove globally. And so this prestige factor plays into—this marker of modernity which I was talking about—doesn't have that much of a cache perhaps in Europe, in Western Europe, and Japan.

Professor Jeffery Hoffman

There's a difference between saying that a country doesn't have an active human space program, which Japan and ESA both do, they just haven't chosen to invest the money in an independent launch capability, which is a very different thing.

Harley Thronson, GSFC

Yeah that's actually the point. I should have said independent. We know they are both relatively lukewarm, they don't seem to show the enthusiasm that say, China has shown.

Professor Asif Siddiqi

Japan and ESA have much larger space programs than, for example, India, I mean human spaceflight programs, they invest a lot more. Japan's involvement with the ISS, ESA. Independent capabilities is an interesting question which has to do with European politics and Japanese domestic politics too.

Question: Paul Ekert, Boeing IDS-Space Exploration

We've got good examples of robotics for space probes or space telescopes, etc., very popular. Many people place value great there. We also have examples of human spaceflight with considerable value. But the issue of robotics, that it's not just supporting science or the astronomy or whatever. That is in between human spaceflight and strictly robotic activities for science. To build up a robotic infrastructure like what you mentioned investments in an infrastructure that's completely robotic which is to augment and prepare for perhaps many human missions. How viable does it motivate the expenditure of necessary dispersals to make that kind of robotic infrastructure that is neither scientific nor exploratory but it's enabling?

Professor Jeffery Hoffman

Well there's different kinds of robotic infrastructure, and I would distinguish between setting up an infrastructure of robotic explorer vehicles, which essentially would extend the range beyond where humans will go in the initial lunar sorties. I think in order to do that successfully, the cost that you refer to is very critical. As I said in my comments, if the best we can do is a billion dollars a copy, it's not going to happen. What I would really like to see, it may sound kind of outrageous, but we ought to be able to turn out small robotic explorers on an assembly line, and if that seems impossible, we would have said the same thing at one time about turning out satellites, but when you look at what's been done for Iridium and Globalstar, they were turning out a satellite per week. If we could reduce the cost of robotic explorers to the point where we could take some risk with them and have large numbers of them, I think what we could accomplish would be incredible. Setting up a robotic infrastructure to essentially assist the development of a human infrastructure is a very different proposition, where you are talking about Earth moving equipment and so on and so forth, and that depends very much on what your ultimate goals are for human exploration. If you're finally going to end up with a large base, then you're almost certainly going to want some sort of robotic infrastructure to help support and construct the base. But I think it's premature to talk about that now because we don't know what our ultimate goal is. For exploration, I think we can see what the advantage of an affordable robotic infrastructure would be, and expanding way beyond what humans can do by themselves. And in addition, it might be very instructive because we would probably learn a lot more about what robots can do which would then inform the development of robots which are going to go to places where humans are never going to be. But that's another story.

Dr. Dan Lester

Yeah, I think there are a couple of things to keep in mind about robotics when we think about the matching of human and robotic activity. First of all, it ought to be appreciated that there's tremendous commercial pressure for improving and making progress on robotic technology. You look at the medical industry, you look at the mining industry. I mean you can just go right down the list and say unlike for human spaceflight, for which we are reaching out for hopefully commercial opportunities, the opportunities to improve on telerobotics is enormous. And you add to that the fact that Moore's Law doesn't apply to humans. Moore's law does apply to robotics. And so on timescales of decades we're going to see enormous improvements in capability. And I think that has to figure in.

Professor David Mindell

And I think you can add to that also that there is a generation growing up not represented by most of the people in this room for whom remote virtual presence is a lot closer to real presence than it was twenty years ago. A few experiments in that realm I think would go a long way. We've been very poor at the remote experience of even the remote spaceflight. And happily I think the lunar X-prize includes a virtual presence component to it. And also to build on what Dan says, in the undersea realm, there are routinely big heavy-lifting unglamorous robots doing subsea completions on oil platforms and specialized tasks that have been designed from the beginning for robotic maintenance and operation. There is an increasing base of sort of real world robotic. Some of it is exploration in the science realm, it's dwarfed in that realm by the practical industrial robotics, and that part of it is only going to grow, and as Dan said there's really a place for the problems of high pressure salt water are different from the problems of the Moon's vacuum, but they're analogous in a few ways.

Question: Dr. John Logsdon

This is specific enough so that I can say it now rather than in the final comments. It's to provide a bit more information on Europe than you pay it in this discussion. Europe has had, since 2001, a study program on human exploration called Aurora, with the ultimate goal of humans to Mars sometime in the 2030s. As part of that program, and occurs to me, David, that it would be a very good thing in extending this paper to get a graduate student or somebody to look at it, Europe as ESA has organized a series of public consultations all over the continent on what the public would like to see in an exploration program. The kind of conversations that you're talking about have taken place in Europe over the past three or four years, and they're not very well known here, and I don't know how they were organized, what the content was, what the result was, but they exist, and we've never done quite the same thing with respect to our program. And the declared goal now of ESA is to develop, preferably in partnership that will work by itself, a human carrying spacecraft as one of its next big projects. There is a move toward European direct engagement in human spaceflight, whether political support for that is there is questionable, but there's the beginnings of murmurs in Japan of the same thing, of if we are serious about having a major space program for the future, it has to include Japanese capability to put humans in space. So it seems to be viewed as part of the portfolio of any leading space program to have an independent capability. Asif's presentation suggests the reasons for Russia, India, and China in interesting ways, but there are other actors that are moving in the same direction.

Professor Asif Siddiqi

I should add that we do cover ESA and Japan in the longer version of the white paper.

Question: Yoshinori Yoshimura

My name is Yoshi Yoshimura, and I am from JAXA. I have a question. First question to answer: why did you choose the exploration as the primary objective? When we started the Space Station program, first one of the primary objectives was to expand our human activities in space, not just for exploration. Other times we do have the concept of exploring in space, but it's through the Space Station. When we first set our space policy, its creators said for the future we have to expand in space.

Professor Jeffery Hoffman

Well in the sense that exploration is the expansion of human experience and capabilities, some of that is being done in the Space Station. But if you tried to justify the tremendous cost of the Space Station just in terms of well we want to set up a scientific laboratory, it would be hard if somebody came to us and said hey I have fifty billion dollars, or chose whatever number you want for the cost of the Space Station, and I'd like to use that to advance the cause of science, you wouldn't chose to build a space station. And so one of the rationales for the Space Station has always been to learn what we need to know the keep humans healthy and functional for long durations in space because that's what we need to know to enable future explorations. Without that justification, the justification politics of the Space Station is very complicated and it would take us a far field to go into it deeply, but I think it has to go beyond just the fact that we want to build a laboratory up there.

Professor David Mindell

We happened to have a lecture from John Tylco in class the other day about the decisions that led up to the shuttle after Apollo, and it's striking in those conversations how much of the rationale for the shuttle was to make spaceflight routine, and you can make the case that historical experience has shown, a.) it hasn't been made routine to begin with, and b.) that argument hasn't been particularly compelling to the American public. So in some sense, the transition that's happened over the course of the last couple of decades has been a return to these I'll say loftier goals on the part of the broad public, not least because human lives are at stake, human lives are lost, and people really want to be doing something that they feel justifies that risk, and of course, many of the crews, all of the crews by definition participate in any of these flights consider it worth that risk, but broadly speaking it's been harder to find living and working in space a rationale policy makers and the public find worthy of the loss of human life.

Question: Dallas Bienhoff, Boeing Company

How would our human spaceflight program, or any spaceflight program, differ if we changed it from sending few handful out to see what's there to enabling the general populous to go, to enable them to go at a whim?

Professor David Mindell

Well obviously at some level, that's going to happen. Probably not the general public going on a whim, but there is this private commercial spaceflight industry. I do think that even a small number of people flying privately, commercially in space will, in ways we can't quite predict, change the public's perception of what human spaceflight means. It's certainly something to be factored in, obviously the technical and commercial risks there are still quite significant, and we don't know how it's going to play out. For example, the companies who are developing those technologies, they're in the business of selling the human experience, full stop. That's all they are doing. They don't have anything else. And so as they think that through, there's also there a mix of remote technologies and I'm not going to pay 200K to fly on a five minute flight, maybe I want my family on the ground in a remote telerobotic, not telerobotic, but remote experience with me. How that plays out technically, culturally, risk-wise, I think will certainly, it will set different baselines for technology, a lot of things, and we

talked a bit about it. I've actually had a Master's thesis or two on it, but it's such an uncertain prospect that we don't quite know.

Dr. Dan Lester

I was just going to say that's a great point, but of course, that's not really a federal policy question. It's not something that the federal government should invest in, which to a great degree is what we're talking about here. I mean, it gets back to the word exploration. Jeff Bezos can call exploration whatever he wants, it's up to him. If he's paying for it, he gets to define the word for him. But what does it mean to the nation? And I think it comes back to the point that was made about Japan. Is the word exploration as opposed to word of what we're going to do. I think that word carries a certain amount of baggage in our culture. Historical baggage. Maybe it's good baggage, maybe it's bad baggage. But we ought to be aware of that. That's a really interesting point about the different perspective.

Mark Craig

There's another dimension here too. Again, the human experience dimension of exploration as it was defined here, if you don't think of it literally as taking, physically anyone who wants to go up, or a small subset of that, but doing it through vicarious experience, which can be obviously technology involved, there are other ways to do that though. For example, flying people who will take people with them emotionally and intellectually. I mean Oprah. Magic Johnson. Fly people that are so engaging and so in the public psyche that when they go, lots of people go with them. And in their training process and everything else.

Question: Unidentified Speaker

A question for Jeff Hoffman. Given the complexity of course of the space walk, I liked what you said about the combination of robots and tools. For space walking: is there room there for a model I would call it surgery operation room, like the astronaut would be able to have this role as assistant, physical proximity, and ask now the scalpel, now take it back, give me a screwdriver, please move this thing a bit little to the left for me. Do you see a need for that? One reason I'm asking is that robotics is slowly moving in this direction and maybe getting closer to doing this.

Professor Jeffery Hoffman

Sure, our mantra for space walking was keep doing useful work. All the time you spend setting up your worksite, configuring tools, if that could be done by a robotic assistant, without getting in your way, it would improve the efficiency of humans to do the things that humans can do better than robots. That's my kind of deciding point. Why have humans do something if a robot can do it? The other part of this of course though is that when you do robotic surgery, it may be teleoperated, but you always have a doctor nearby in case something goes wrong. And I think it's that cooperative aspect will continue to be important. But I think, in fact I carry this idea further as a design principle for mechanisms that should be serviceable. I think one of the best design principles is wherever possible, design something for robotic servicing. Now some people think it's more difficult to design for human servicing, but I actually suspect that when you really get down to the nitty-gritty that people will find if you're really trying to design something that robotic technology is capable of operating, in many cases it's going to be more difficult than designing something that a human can operate

because we're a lot more adaptable and flexible. But if you start out with that basic design goal, then if the system runs into difficulties and our robotic technology is not able to cope with it, then at least the humans are going into a well designed, fairly simple interface, which I think gives you a head start. And of course the other aspect of it is certainly true, like Dan said, that human capability is not expanding with Moore's Law, but there's an awful lot more we can do to improve the efficiency of our spacesuits and our gloves and our tools so that humans can actually do more of the things that humans are capable of doing. There's a lot of things you can do in that area.