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Panel 2: Human Spaceflight and National Priorities

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Let me kind of start to kick off the second panel. Thank you all for coming. My name is Scott Uebelhart. I'm a postdoc with the MIT Science, Technology, and Society program working very closely with David Mindell on the Space, Policy, and Society. I'll have a couple of remarks first trying at least to frame the policy implications or how we are thinking about this in our group and kind of introduce, let the other members of the panel speak. The previous panel was much more conceptual and focused, really trying to address the question of why would governments fly humans into space in the first place. I kind of put up here David's original slide kind of showing what we call first of all the framework, primary and secondary objectives, where the primary objectives must require human presence, be worthy of the opportunity cost and be worth the risk to human life. Where the secondary objectives, then, have benefits that accrue from human presence by all means, but don't necessarily justify it on their own means.

The point of this panel is to focus more on the implementation side of things. After the framework, there are the objectives. We define them for ourselves as exploration, national pride, global leadership, you can perhaps argue about what ones should or should not be there. This panel's role is how to transition from the objectives then to what are the policy implications and ultimately the policy decisions. This kind of area is one where we recognize there is going to be the most debate, the most if not contention then questions that are raised. So what I'm going to try to do is lay out a framework for maybe how to think about it and then just kind of open that discussion. What are the implications of these primary objectives for thinking about this? How do we align policy decisions with these objectives and how do we align these decisions ultimately with the national priorities. Let me first describe kind of the first steps our group up at MIT took in apply this framework to the policy issues. How are we going to begin that transition? We asked ourselves if we really, truly believe that those primary objectives are the reasons to have human spaceflight and we can make policy based purely on them, what are the policy implications? What kind of space program would we have? And one implication is that we are going to chose and implement projects which are not achievable in any other way and worth the risk. Again, I recognize that this is a circular argument, but let me use it to kind of think about what type of program might we have, what are the implications? One is that it would probably lead to a very different program than what we have today. Kind of look at the past and then discuss the Space Shuttle. I suggest that the Space Shuttle would not necessarily meet the primary objective criteria. The objective of the Space Shuttle, and I'm quoting actually John Logsdon's paper, was to replace all existing, expendable launch

vehicles. To launch satellites for the government, particularly the DoD. This was the kind of high level objective that influenced the design choices and ultimately kind of went down and influenced a lot of the technical decisions that were made. Certainly we could argue that human presence is not required for this, and after the Challenger accident, that's exactly what the nation said. Ferrying satellites into orbit was not worth the risk to human life. Members of the Columbia Accident Investigation Board kind of expanded that then saying well alright, what is worth the risk to human life? And that's kind of why we're here to argue.

So then we can consider what type of program would these objectives lead to? Well kind of transitioning again from the objectives to the implications, you know, we also need to acknowledge, Scott Pace helped us think about this, the different value judgments people are going to have on these objectives, and these can kind of be a key component as well. Different nations, different individuals are going to value these objectives separately. Asif Siddiqi in his comments in the first panel really talked about how it's national pride that motivates many of nations that are just starting a human spaceflight program. National pride in this country may not mean as much as it did certainly back in the sixties. You know this country, again its idea is certainly exploration and international prestige. Those are the ones that we kind of value, but even how are we going to take those concepts and move them forward? Really also depends kind of on the own judgments that we bring forward. But when you really start talking about values, now you can just see how you can connect this framework to the idea of national priorities that ultimately influence those values. And well all kind of know what those national priorities. What are the national priorities in this country today, and we all know what they are. Economic development, stimulus packages. Energy, climate change, healthcare, wars in Iraq and Afghanistan. And the important thing for the human spaceflight direction is that these policy decisions must take place, policy decisions for human spaceflight really must take place at the intersection of these priorities and the primary objectives, and it's the intersection which is important because if we're trying to use human spaceflight to address certain national issues, whatever they may be, and we believe in this framework, that the primary objectives must still be key, we have to use these tools in ways that require that human presence, in ways that actually address priorities that can actually be solved by the presence of humans in space and not necessarily for other purposes. Take for example the idea of using human spaceflight research for energy or climate change. The International Space Station is clearly a fantastic laboratory, or could be, a fantastic laboratory for use in this sort of research. It's showing examples of state of the art air and water recycling, state of the solar voltaic panels. So if you had the ISS up there, clearly you're going to want to use it for many of these purposes, but the question is do they justify the ISS? Do they satisfy those principle objectives? We certainly would suggest that and in many of these cases, no, they don't. They don't perhaps absolutely require the presence of humans. Something that is helped and motivated by the presence of humans instead, but would necessarily develop an ISS just for the purpose, just as we should not develop a new human spaceflight purpose to address national priorities that don't necessarily have benefits accruing from that human presence in space.

Obviously these decisions are not made in isolation. Another point that I think Scott Pace was good about helping us point out. Clearly when we're dealing with a political sphere, different statecules are going to respond to different applications, and I think we're perfectly aware of that. We certainly don't mean at all to put down this idea of secondary objectives. They're obviously critical, they're what all of us work on for the most part; they require the support. But again, to use kind of some of Mark Craig's discussion from this morning, we're trying to get the most benefit out of the space program for long term policy sustainability and robustness. You know the programs and again the technical decisions need to be centered kind of on the

principle objectives of the endeavor, the idea of having that attribute of human presence. So I think the usefulness of the framework and our approach to transitioning from the objectives to the policy implications is not necessarily to isolate decisions from the political process in some sort of pure sphere of exploration or pure sphere of international cooperation. But rather try to frame and identify those issues where the driving objectives upon which, really trying to focus the issues on what are the fundamental objectives of human spaceflight.

So with that kind of introduction, let me ask a couple of questions for the rest of this panel. First of all, I really am looking forward to everyone else's perspective on what are implications of this kind of framework on the policy and ultimately, how do we begin to align some of these policy decisions and some of the primary objectives with national priorities that we're facing today. And I'm really looking forward to hearing what the other panelists who have actually had to really deal with a lot of these critical policy decisions will have to say. So let me kind of take the time now to introduce the rest of our panelists. To my immediate right is John Tylco. John is the Vice President for business develop of Aurora flight systems. It's a midsize aerospace company whose offices are actually located right next to MIT. John has been a member of our policy group and has really informed a lot of our discussions. He also has managed to figure out how to get himself a press pass from NASA, so he's has absolutely fabulous pictures of Shuttle launches, which you'll find in Aviation Week, which I highly recommend. Next to him is Wayne Hale, currently the deputy associate administrator of Strategic Partnerships. And course before that the Space Shuttle program manager. Several weeks ago when we were trying to put together this panel, we wanted to have a current NASA representative on this, and it was about that same time that Wayne emailed us expressing interest in just attending in the audience, and we very promptly invited him to participate, so we thank him for allowing us to shanghai him into this panel. And lastly Scott Pace, director of the Space Policy Institute, before that the associate administrator of Program Analysis and Evaluation at NASA, and someone who has along with Jim Lewis here at CSIS who has really helped kind of David and I come up with the structure of this forum and really help push this along, so we thank him for that. And with that I will kind of turn the table over to him.

Professor Scott Pace, Director, George Washington Space Policy Institute

Hopefully we'll have time for some discussions as well at the end of this. First of all I also wanted to thank both MIT and CSIS for pulling this together. I appreciate CSIS for hosting us here and have this discussion. As some of my students know, I'm fond of little 2x2 matrices, I'll concede I picked it up from a political science class one time, and one of the things that I use is to structure the different competing objectives that we often try to trade off in the policy world. I'm going to give you an example of this. As Scott mentioned, the terrible Challenger accident raised the policy question of should we be using Shuttles, should we be using humans to launch satellites into space that could be done with unmanned vehicles, and the answer was, well, no, we shouldn't, we should use people for things that are really unique. So then later when Columbia occurred, a more profound question was asked which was well, for what purposes is risked human life worthwhile at all. And then the Columbia Accident Investigation Board came back and said, well for whatever it is, we need to be going beyond low Earth orbit because simply staying in low Earth orbit isn't really

playing for high enough stakes. So then you had the vision for space exploration as an answer, one possible answer to what moving beyond LEO might be like. Those events of asking questions are things that I think are all too rare in the human spaceflight community. Too often, since President Kennedy said where can we beat the Russians and going to the Moon was an answer to Kennedy's political question, we don't really ask human spaceflight. We get human spaceflight, the answer what was the question. And I think that the human spaceflight community could learn a lot, take a lot from the science community, which asks very simple and profound questions. They're simple enough that even Congressional staff can understand them even if they don't understand the answer that comes with it. Like what's the nature of Dark Matter Energy? Is there life elsewhere in the universe? These are really almost existential questions. And then from them you have a program strategy that flows down and says we're going to follow the water, and following the water we're going to have an experiment that going to look for different kinds of water, and this will hopefully look for other kinds of life. And so there's a chain that leads from a very basic motivating question to things that then allow you to judge your program and project as to whether it's contributing to answering that question.

Now my favorite in question came from a guy named Harry Shipman. He wrote a 1988 book called *Humans in Space*. And he said that two big questions are can you live off the land and is there anything interesting to do out there? And if you answer yes to both questions, then you get space colonies and space settlements. If the answer is no to both questions, then you get Mount Everest. Nice place to visit. Someone makes money taking you, Sherpas making money taking you up there, but no one lives there. If the answer is somewhere in between, it could be like a North Sea oil platform that you go out and service, but you don't really live there. If the answer is that you can live there, but there's nothing really terribly economically useful to do. Kind of looks like Antarctica, and again tourists and scientists maybe go there. Those are four very different human futures in space, and I run into lots and lots of people who are convinced that they know which one is right and which one either will happen or should happen or must happen by manifest destiny or whatever. I submit those are all faith based, you initiatives which have their place and role but aren't really true. You don't really know which one of those outcomes is it. So I think a profound question for the human spaceflight community to answer and maybe something in the terms of what exploration might answer for us is which one of those human futures is right. And to answer that question, one then chains into a whole bunch of subpieces. Institute research utilization, how long, weightless effects, high reliability software systems, commercial activities innovation in space, what's the right regulatory environment to encourage commercial activities? I mean you can go down and make a giant tree that descends out of that question, and then be able say, well how well are we answering that question or making progress toward it.

Now a simple version of the near-term use of these kind of frank questions and framing I think is going to be the International Space Station because one of the debates of the budget is how long does the Space Station go beyond 2016? The answer the OMB would probably like to hear is zero and the answer the international partners might like to hear is forever and there's somebody maybe in between. I submit there will probably be two factors that will drive it, one is are we getting useful R and D or other benefits out of Space Station and how's the operating cost? If we're getting R and D benefits after it's running as a national lab for maybe five, six years and the operations cost can be brought from say two billion down to let's say one billion, the answer's probably sustain it and continue it. If the answer is after five, seven years we're not getting much out of it and it's still costing us two billion dollars a year in current dollars, the answer's hmm, time to think about deorbit. Now the problem is that you cannot answer that question right now *a priori*, you have to run the

experiment. You have to complete the Space Station, meet the international partner commitments. ISS as a national lab, which I initially thought of as that's kind of a stunt, just putting that label on there, I've come to see as that's really pretty smart because you want to run the experiment of ISS as a national lab with a whole bunch of other people working there, commercial, scientific, international, so you can make an informed data based, fact based decision as to what you ought to do. Now again the science community has an analogy for this. It's called a senior review. They don't run science projects forever; Mars rovers might be an exception. They actually try to answer, well, gee, is this really worth continuing because if we continue to operate something, that means there's some new start we're not going to begin, so rather than just doing a case by case analysis, every couple years you have a senior review, you rack and stack the programs up and you go do we really want to keep doing this? And you have to have facts to base that on. So again, asking questions, having senior reviews, judging benefits. There's some chart I think Mark had one there about external reviews. Now those external reviews I think would be an excellent idea for a human spaceflight program, but not if it's asked solely in terms of a narrow discussion of how's the peer reviewed science and how many journals have you got published in Cell this week. That is an overly narrow definition of course of what the human spaceflight endeavor is about, but the idea of external reviews, the idea of asking questions I think is very, very valuable. So in that regard, I really like the framework that MIT has proposed as a means of asking good questions. As a former policy practitioner, I'm less enthused about using it to inform debates over the FY10 budget or what fight at run-out is going to be because it poses questions that I think are very, very difficult if not impossible to answer upfront. These are things to sort of debate and understand what policy preferences are, but you can't really answer how much science are you going to get out of something. How much international cooperation is going to come from this? These are experiments that have to be run. So I suspect that as with all presidents that this president will shape the space endeavor, the ultimate discretionary activity to suite his needs as every president before him has. I think there are opportunities for space to link up to some of the top level objectives of the economy, the environment, international cooperation, and science and STEM that this president has talked about. The question is whether or not those opportunities will actually be realized is still something to debate, and again, when looking at opportunities coming forward, yet another Augustine commission, I remember the first one nineteen years ago and here we are again. If it's scoped broad enough, to look at these bigger policy debates, I think it has the opportunity to be a great success. A repeat maybe of the gathering storm effort but maybe the gathering storm for space would be I think a broad scope effort that would serve the nation well because the alternative we've already experienced. We experienced it with the Shuttle program. The Shuttle program was a policy failure for many reasons that Dr. Logsdon has written about which I had fun with with my Master's thesis at MIT because the policy debate didn't happen. Instead of just having a discussion about what do we want to accomplish in space after Apollo and what are different means of getting there and what kind of architectures might do that and for what ends. For a variety of reasons, the debate devolved down to a cost-benefit analysis. But there was no policy input. There was no policy other than get the peak funding down and keep the overall cost under control. And so as a result of that lack of policy debate, a chain of tragic events unfolded where we defined the Shuttle not in terms of what we were accomplishing for the country, but it's going to pay for itself. And of course with large fixed costs you know how often you have to fly to amortize those large fixed costs then that then became the goal and then the goal had to be met because that's why the program was being done, and you had a decade or two of fantasy that ended in tragedy. And that was a result of not asking questions, of not having a larger policy debate, and of letting narrow but

valid, however valid analytical techniques drive what should have been a national level decision which I'm hopeful we're going to have today. Thank you.

Wayne Hale, NASA Deputy Associate Administrator for Strategic Partnerships

Well I find myself in an odd place. My career's been spent as a person who executes national policy rather than informs national policy, and it's a very odd thing I think for me to sit on a panel, but it may be helpful coming from that prospective to provide a few thoughts as to the results of national policy and how they impact those of us who are charged with executing national policy. Before I do, I thought it was kind of interesting that we're talking about exploration and the justification for human spaceflight and yesterday I received a copy of Senator Bill Nelson's speech that he made on the floor of the United States Congress Senate which I think whether you think it's actually correct or not represents the mythos of why we go into space, and from which national myths we derive our political values and in fact our political power. And I'll just quote a little bit from his speech as he is a policy maker and I am not. He said

"The United States was born because human beings are driven to explore the world around them. Christopher Columbus's expedition discovered the Americas, President Jefferson dispatched Lewis and Clark to a two year expedition to chart North America, and an American named Neil Armstrong became the first human to set foot on another celestial body. Each of these grand voyages came at great public expense and grave risk, but to the nations that undertook them, this desire to venture out in new directions has brought amazing new advances and change for the better, and our most recent voyages have given us fire-resistant material, weather forecasting equipment, scratch resistant lenses, and certain kinds of laser surgery just to name a few. Our modern day expeditions have also given us heroes; men and women who put their lives on the line for the benefit of all of us and for generations to come. President Obama understands this. He knows why we as a people must explore our universe."

And further down in his speech in ramp up he says "we cannot deny who and what we are. We always have been and always will be explorers. Our great nation would not exist if it were not so." So whether or not you think that's a valid argument, it certainly comes from the national mythology of frontiersmen and explorers, however you define explorers. And as a justification for some of the policies that are given. Which goes to the chart, I think it's on the screen.

But what I'd like to talk about for just a second is the intersection of policy and making spacecraft and how those things affect making spacecraft. I have a little video I want to show you. There are a number of lessons learned from any number of NASA missions. Harley probably has a hundred he could talk to us about. This is one that was particularly near and dear to me as Shuttle program manager. And I use this as an engineering example, but I think it's also a policy example. Let me run this little high speed video from a camera of a Shuttle launch looking at the outskirt of the solid rocket booster at the time of ignition. It's twelve seconds long, so you can watch this on the screen. And the problem I think is immediately obvious to the casual observer. Actually this was STS-112 in about 2007. The Shuttle as you know is held. The orbiter is bolted to the external tank and the external tank is bolted to the solid rocket boosters, and the solid rocket boosters with

eight very large bolts are held to the launch pad. That's what holds the vehicle to the launch pad. When you ignite the solid rocket boosters the signal is sent to fire the pyrotechnic bolts to let this hold down release. And what happens in this picture is what's not supposed to happen. Right here is about a three inch threaded stud diameter. The pyrotechnic bolt is up here in the blast containment housing, it's already blown. And this stud is not supposed to actually come out of this hole, it's supposed to fall down under tension down below. What happens is because there are two pyrotechnic devices on the bolt that because of delays in the firing circuit fire milliseconds differently. Instead of the bolt popping apart, you get an activity of where one side opens then the other side opens and it forces the stud up against the cavity in the aftskirt of the solid rocket booster and it holds on. We call it a stud hang up. Stud hang up. And it occurs in about fifty percent of the Shuttle time. And you see the stud falling back down and the container out of the hole where it's supposed to. Now the interesting thing about all this is when it releases you notice the stud is bent over and when it releases there's a twang that goes through the whole system. This does not hurt the solid rocket booster whatsoever. However, that twang gets through the entire structure and gets into the Space Shuttle orbiter run by a different group of people at a different spaceflight center and in fact under certain combinations of multiple of these hang-ups, and we've had about ten percent of the launches where we've had multiple stud hang-ups, that is to say we've had more than one out of the eight. In some wind conditions, you could put a strong enough load that you could actually physically break the tail off the Space Shuttle orbiter. This is not a joke. This is a serious thing.

So during my tenure as program manager, we decided that this was a problem that should be fixed, we should eliminate this problem. So we tasked the Marshall Spaceflight Center and the solid rocket booster folks to improve their pyrotechnic device which they were able to do by merely cross strapping right there the pyrotechnic device and eliminating the delay so the separation you eliminate the cause of the problem. For twenty years, we had studied this problem and spent untold engineering hours trying to analyze permutations and combinations and what effect this might had. Every Shuttle launch we had a probability risk analysis and all those kinds of things and we spent I don't know how many millions of dollars impossible to resurrect studying this problem. This is one of probably ten thousand engineering case studies I could give you.

So I went to the Marshall Spaceflight Center where they were testing this cross-strap bolt because of course you want to make sure it works properly and certified and I talked to the people on the floor, this was about 2006/2007 timeframe, and they said you know what Mr. Hale, we had this cross-strap bolt ready to go in 1984. It was almost certified. We almost put it into work. And I was flabbergasted. For twenty plus years we've been living with this problem. And I said why didn't we implement it? And they said it doesn't really cause any problems to the solid rocket booster; this is just cosmetic damage inside the hull here and the budget was cut and in our project our budget was cut as all the projects were and so something had to go and so it wasn't causing our project—the solid rocket booster project—any problem so we eliminated the improvement. And so for twenty years another part of the program paid untold millions of dollars. When you try to do something complicated, and spaceflight is terribly complicated and has a low factor of safety and on and on, then you run into these things. I would echo the words of John Kennedy when he said if we decide to go to the Moon and stop because it's too expensive or too dangerous before we complete the task, it would be better in my opinion not to go at all. So these systems are expensive, I'm sorry. I wish it was different. My experience is that they always have been and they always will be. At least in our current technology, and unless they are fully supported by adequate resources, remember Kennedy's mandate was very simple: Man, Moon, Decade, and the resources that went along with that. To send a man to the Moon and return him to the Earth before the decade

was out, Man Moon Decade, within with the adequate resources. So whatever policy, those of us who have to execute it would merely ask that we have the resources commensurate with the task. I would show one other movie and then get off the stage and let the policy people continue. This is not computer generated, this is not Hollywood or Soundscreen or some video game. This is people going into Earth orbit. As Robert Heinlein, the great science fiction writer, said once you're in Earth orbit, you're halfway to anywhere in the universe. This is real, this is actual, this is an accomplishment. I think that it's time that go past halfway and anywhere in the universe. And with that I'll turn it over to the next speaker.

John Tylko, Vice President for Business Development, Aurora Flight Sciences

My background is entrepreneurship in electronics, software, and aerospace, so I'd like to focus on two topics that I think are extremely relevant to the future of human spaceflight that have not been talked about by the other panelists. One is the role that the inspiration of human spaceflight plays in encouraging the next generation of scientists and engineers to study science and engineering and enter the industry. And then the second is the economic development that occurs from spaceflight related programs in terms of accelerating economic development in the national economy. And I think both of those topics are extremely relevant to the current administration both in terms of short-term goals of job creation and economic recovery but also in terms of long term goals of sustaining our technological superiority in the future through a generation of engineers and scientists that are trained and educated to achieve those goals. And I think in my generation growing up during Apollo, both of those things were significant players in encouraging students like myself and probably most of the people in this room to study math and science and pursue university educations in those fields. And also looking at the role that Apollo played in technology development. The best example is the development of the Apollo guidance computer at MIT in the 1960s, which really advanced the state of the art in integrated circuits in the mid-60s. The MIT instrumentation lab procured something like a third of the national output in integrated circuits in order to accomplish that mission, and that drive to develop that technology played a major role in the growth of integrated circuits over the next several decades. So how do you translate that into policy that might be effective and what has to be done to accomplish both of those? And by the way, I think those goals are extremely interrelated and in fact somewhat codependent that that process of educating the next generation of engineers and scientists directly ties into the ability to develop new technologies that then fuel economic growth.

First off is how to inspire the next generation of scientists and engineers. And I think this is a critical disconnect. The communication that we had during the era of Apollo was quite extensive even though we only had three national TV networks and the local newspaper to get the message across. Today's generation communicates via a completely different approach. They don't read newspapers, and I don't think they get their news from television, but things like blogging, twitter, social networks, youtube, interactive virtual reality via things like video games, and then making NASA TV more relevant. It's a great resource that NASA has. In fact the National Space Act that formed NASA in 1958 lists education and outreach to the public as one of the primary reasons for agencies existence, yet I think it does not do the kind of job that it could do to really promote and encourage all aspects of making spaceflight accessible, interesting, compelling to young people,

making it relevant and particularly exciting. So I'm a strong believer both at the in terms of encouraging that inspiration, and part of that leads back to the university level. NASA was extremely aggressive in the 1960s to build facilities in universities for aerospace, sponsor fellowships for graduate students, and to have NASA sponsored research in fundamental science and technology. That for the most part does not exist today. The fundamental research has been dramatically reduced and I feel quite strongly that those key elements of driving university education and research towards aerospace related topics has a tremendous benefit in terms of economic growth.

I think the next step in terms of making spaceflight and human space exploration in particular play a contributing role as an accelerator in economic development, it has to consciously undertake ambitious, strategically planned development of technologies. For the most part, in the last decade or two, we've relied a lot on commercially available off the shelf technologies, and what I would suggest is that we need an ambitious, strategically planned development of critically needed new technologies that would truly advance spaceflight in areas like advance propulsion, autonomy, electronics, computers, and software, and life sciences as being examples of places where those resources could be best applied. I think another element is to encourage entrepreneurship. I think young organizations which are aggressive, resourceful, ambitious, and cost effective can play a key role in driving technology development that's related to spaceflight. And I think in a large way that would result in encouraging competition with new companies that can take those advantages, particularly relevant to the larger space primes which have been extremely concentrated in recent years, and I think have resulted in becoming less effective for both cost and schedule performance, and that has a direct relevance to the resources available and the rate at which new programs are able to be brought forward. So companies like SpaceX, companies like Orbital Sciences, these are entrepreneurial driven companies that I think could make a tremendous difference in how this space technology is actually developed. So I believe that we've discussed these as secondary priorities, but I think they're actually fundamental, and I think they're both the education component as well as the new technology driving and accelerating economic growth is a big part of what makes human spaceflight relevant to politicians and perhaps relevant to the Obama administration. Thank you.

Questions

Question: Dr. Scott Uebelhart

Let me ask that first question to the panelists: If we're talking about exploration as the ultimate goal, how in your minds does that translate to what are the policy implications of that, what are the technical decisions even that would result from a clear statement that the human experiences we are trying to get, the science and whatnot are secondary. What results from that?

Professor Scott Pace

I think the first thing you would get is a large food-fight, which would probably lead to a standoff inside of the Congress. The problem is the policy direction has been largely laid out and one can sort of tweak it. What I've noticed about the current debates is they're questions about how do we do this not whether we do this or they're about what combinations of components do we put in, what kind of emphasis do we have on education here or what technical fix do we need to make there. I think what's been remarkable for the last couple of years is that the space exploration vision that was laid out in 2004 has become more of a bi-partisan support if you look at what happen in the 2005/2008 bills. So I think asking the question how can we make our direction better, more effective, put it on a sounder foundation, be more confident about where we're going, meet other national objectives I think those are very, very fair and reasonable things to go look at and I hope the review that goes on does go look at those things. But I think if you go back to bare wood, that is you try to say why are we doing exploration at all in a policy realm as opposed to an academic realm, I think you risk creating a larger debate that will then sort of freeze what progress has been made. Political people hate fights among technical people because they don't really understand what's going on, and therefore the easiest thing to do as a political person is then to say until the scientists settle it out, we're not going to do anything. Now the technical fights that occur within the space science community or Earth science community are a little better because you have the National Academy of Sciences. You have a group that says we're going to fight among ourselves, lay out priorities, and once the scientific priorities are out, then NASA will figure out how many of them they can afford and program in. So the fighting is constrained to a particular forum. We don't ask fundamental questions to Congress, do you like Earth science this year or do you like space science this year. We channel that. The human spaceflight community I think should build on the consensus that's been so painfully established in the aftermath of Columbia to then have these sorts of reviews, have these structures, have these fights, technical arguments and policy arguments, but to channel them in a way to become meaningful and actionable for political folks to do and to leave some of the more basic exploration questions that I advocate looking at for the academic realm, for the think tank realm to debate. I don't know if we can quite parse it so cleanly, there will certainly be an amount of bleed-over, but I would be very careful about opening up fights where maybe you've already made some progress.

Wayne Hale

Well I guess I'll start. The Columbia Accident Investigation Board said that NASA safety had largely been silent and it's not really just safety, but as you'd say the engineers which are the true backbone of understanding what's going on. As part I think of the real culture change that came in agency after Columbia we have put a lot of backbone into folks and as we see in many of these technical issues, they are willing to

stand up, and one of the things I see in the Constellation program is we're designing a new vehicle. There's a great deal of emphasis from the engineers and the safety folks to what is possible, what is practical, what is safer. I hate to say, the Shuttle was, is my baby because I worked on it all my career, and it's an ugly baby. Scott called it ugly just a minute ago. It's still painful for me to hear that in public even though it's true. So what we'd really like to do is have something that is significantly safer, but when you're going out on the edge of technology, it's never going to be safe in the ordinary human being sense. What side of the line you are on is very difficult when there isn't a bright line that says you've crossed over into unsafe territory. By definition, we're operating in unsafe territory.

Professor Scott Pace

One of the things I would say—and Wayne's comment applies even to more familiar things like aircraft—when you go into aircraft accident investigations, and you peel back what's going on, there's operator errors and there's design errors. At some point, you get to where engineers have had to make a choice about risk. Nothing is never 100% safe, so you're always making this sort of tradeoff. So the question is was that tradeoff done consciously, explicitly, was there an understanding of the system's impact, are those kinds of trades, how things were made. I love Wayne's example of the bolt because that exemplifies a lot of the problems in Shuttle, which is not technology per se, but it was the system engineering and the interfaces between the different parts of the organization. It was an organizational design issue, which went to the heart of when the program began, which is how it was going to be developed, where you had these interfaces and where danger occurs. I draw a distinction between R and D operations and development. R and D we all know and love and know how that goes. The ops world, which particularly I think Wayne was in, brilliant, brilliant work, but with a defined problem, with a defined universe. The developing world we're now moving into with Constellation is the worst of all worlds for an engineer because it's also the most challenging. You never have enough time. You never have enough money. You don't know what analysis you're doing. The thing keeps moving. The requirements are in flux. You're taking risks. You're making judgment calls. They are almost artist at some point, not particularly always analytical. Therefore there's a high degree of reliance on people who've been there before, have had experience. And of course we have people who haven't had that much flight experience. We haven't had people who've been through three of four other development programs before they got into this one. And so one of the arguments to me for doing large scale develops like this is that space is the most interdisciplinary system engineering activity that this nation can undertake. Every discipline is involved in it. In order to accomplish something difficult in space, you have to bring all those disciplines together, and to make them work is no bigger challenge. I think we've lost a lot of that capability. I worry about this country's ability to carry out high challenge system engineering endeavors. You don't have to look far at other things, from air traffic management to telecom systems and cybersecurity, the future of the nuclear weapons complex. Whatever you look, you see large scale systems engineering challenges, not to mention the entire defense establishment. So to me, the space program is also a giant learning tool to train capabilities for the nation to have national powers that it needs to be a global power, as well as being educational in its own right. It comes down to those little nitty-gritty points that Wayne was pointing out about the gaps between different parts of an organization, how people solve that. That's the pointy end of the spear for where these capabilities are developed or lost.

John Tylco

I like to just add I think the critical decisions on the Shuttle development occurred between 1969 and 1972 when the policy makers, particularly in the White House and OMB, were heavily involved in articulating a cost driven strategy to the engineers. If you look at Apollo, it was Man, Moon, Decade, and effectively performance and schedule were the drivers and cost was an independent variable. The NASA culture, in fact it was largely the same team of engineers applying their skills to Shuttle were now faced with cost as the primary variable in an environment where the Mathematica study that analyzed the cost implications of Shuttle also was delving into, economists were delving into technology trades suggesting solid rocket motors would be more reliable than liquid propelled engines. So all of that trade, it's sort of a major cultural difference with the same team. Max Faget, Mercury, Gemini, Apollo, started working on Shuttle designs in 1969. You can't say that it was the team or that it was the group think. I think it was more that it was the imposition of very strong cost driven goals, largely from OMB, and Scott Pace's thesis covers that topic really well.

Professor David Mindell

Scott's point about not letting the policy makers worry about some of these questions because there is a case to be made that if the decisions are being made with at least an appreciation of systems engineering process, some of the tradeoffs, and the way that the high level principles on which the policy is made impact right down into the nuts and bolts, literally in this case, then you run the danger of a Shuttle-type situation. A policy is set with particular political priorities, which it's always going to be, but then having ramifications through a system design that is not what you want.

Question: Unidentified Speaker

I'm very good friends with him, coauthor of the Mathematica study for the Shuttle economics over which we have destroyed many a good bottle of scotch discussing, but at least Dr. Heiss's opinion, if I've got it right, was that Mathematica was just looking at broad architectures as was actually prohibited from making technical analysis, something from which he is hugely disappointed because he was personally appalled that the decision was made to use large solid rocket boosters. While they looked at the payoffs configuration and the cost reduction development, they were prohibited from going in deeper because he had wanted to have liquid boosters, but my observation was that there was nobody on the Shuttle development team who had a whit of understanding about what the life cycle decisions were going to be, and they were constantly trading away life cycle impact or trying to hit performance numbers in the field. That was something I saw just going back and looking at some of the engineering studies later. I would say that they were culturally or at least from a mantra point of view blinded to any decision that would occur after the first launch. They were driven to achieve launch one covering certain missions and don't worry about that, that's someone else's problem, I won't be here. That was very much my perception of that.

Dr. John Logsdon

Just for the record, it is true that the memo that Dr. Morgenstern and Dr. Heiss sent to Jim Fletcher in November of 1971 recommended the configuration have thrust assisted orbiter and pressure thread liquids not solids. So you're right on that part. There's a classic letter from Jim Fletcher to OMB to George Schultz of December the 29th, 1971, which makes the other point. It tried to get close to the OMB boogey saying

development costs of the full size orbiter would be 5.5 billion dollars, and at that point even before that decision was made, pushed the operating costs totally downstream, said that the operating costs per flight would be 7 million dollars. There was no analysis under that number. It was just that number. So it was built into the structure of the program, that the operating costs were something that someone else would have to worry about. I hope we don't do that now by the way.

Professor Scott Pace

I think that's one of the positive things about the current environment. Precisely because some of those lessons, that even the arguments about the ESAS architecture that are going on and people having these sorts of debates. There is I think an awareness of ops costs. There is an awareness of the multiple reasons why you might be doing something. So on one hand, I guess I'm occasionally bummed by the fact that we're still having some of these debates. On the other hand, I compare where we are today to the nature of the policy debate in 1972 and even 1991, and we're incredibly better off in terms I think of the maturity level of the discussion, the involvement of international, the involvement of commercial, and I think the realization that we have very serious system engineering problems that have to be grappled with. When I arrived at the agency in 2000, I guess 2001, there were memos and briefings coming up about we need to be doing studies about flying the Shuttle through 2020, which in retrospect I thought, gee, that seems kind of not really a good idea, but I wasn't Wayne Hale or any of the rest of the guys who the real hands on. I just went hmm, I don't know about that. And what I've seen since Columbia is exactly the culture change that Wayne talks about. There's a great deal more humility, I think, in front of the hardware now than I certainly perceived earlier. And that humility I think is informing the architecture. The ESAS architecture itself was the first architecture that I'd seen in 15 years or so where I looked at it and said I think I actually know how to build that, and this is coming from somebody who's too many Bob McCall paintings in his basement with national aerospace planes and other magical items. What are we going to actually do, and again the point about people actually flying and heading out into space, not airbrushed drawings, but what do we really build, what do we really fly. At least we're having that debate now, which didn't occur for many, many years.

Wayne Hale

And I've got to say, a lot of the decisions that are made at the program level in the Constellation and in recent years have really looked at life cycle cost and they've driven design, and in fact driven up the early development costs and delayed I think some of the schedule based on having a life cycle cost that would be lower than alternatives. So that's a real consideration in the design of this vehicle.

Unrecorded question

Professor Scott Pace

I thought some of the previous presentations which talked about eliminating destination and talking more about experiences because otherwise you run out of destinations that you can do without warp drive. That's why I like questions. I like questions about what is the human future in space. Are the economically useful things to do off of the planet? Can you live off the planet? And answering question is Earth the only home for humanity. Again, people have faith as to what the other alternatives are, but to answer the question, I think you take destination out of it. If you ask a larger, framing question about what is humanity's future, and I

would posit that spending a few billion dollars answering what humanity's future is is comparable to spending a few hundreds of millions of dollars to discover dark energy. These are large abstract questions that maybe aren't part of putting daily bread on the table for people, but they're things a great nation does. They're things a leader does. They're things which have the ability to pay for within reason out of our other national treasure, and as long as we're not ridiculous about it, I think we can and should pay for these things as part of what a great nation does.

Dr. Scott Uebelhart

And I'd also add one of the things we are talking about with this idea of exploration, this idea of expanding human experience. We never really even got into the debate about where are you going to do that. At what location expands human experience better than others. If you're talking about all the destinations, there seem to be a lot of debates going on there that don't necessarily relate to, again, what we call the fundamental objectives. If the debates are scientific, that Mars has better rocks than the Moon, well, okay, but you can send robots to see there. If it's more about Scott's point, whether or not we can live off the land, perhaps that's a technical debate, a question we talk about in a forum like he discusses. But there are obviously still two sides to about ice there ice in Shackleton's crater and all that. If on the other hand we really try to frame the basic objective of expanding human experience and trying to show human presence outside Earth, show whether or not we can do that, to a large extent we are succeeding with that right now. The ISS perhaps is not exploration in the vision for space exploration, it was more or less almost abandoned, but it still is an example, it still is a destination where we're showing a new way of living. If you frame the question I think a little differently and I think a little more to the experience, then I think to a large extent I think it becomes let's show couple of examples of where we can go and ultimately decide some of that based on Scott's test or even perhaps budgetary decisions. The Moon is obviously a lot cheaper than Mars is going to be. We might get some of the same response from it.

Unrecorded question

Professor Scott Pace

I tell this story a lot and some of my Air Force friends are getting tired of it, but during ESAS we went looking for system engineering expertise in the Air Force as James Webb did in the back in the 1960s, and he got Sam Phillips and a bunch of ICBM guys in. And the answer is we really didn't find many people in the Air Force who had relevant experience. We found a couple, maybe a handful, but really not very many. There was no talent to steal. I think that's one of the reasons that the Air Force and military space programs have had a number of very, very serious problems. I think that some of the challenges the human spaceflight programs has, particularly at JSC has been that lack of developmental experience. If you look within NASA, where does some of that developmental experience, which is really again more of an art, that experience rather than just direct technical subject matter knowledge has been some of the science, there is again with limitations and problems, but within places like Goddard and JPL because they had in house work. They had people with hands on experience, and therefore they could be more than just a paper pusher as a COTR, they could actually know what they were talking about. We have done a poor job over the last several years of creating opportunities for young people to get hands on experience. We have done a poor job providing opportunities for NASA civil service to get more hands on experience. That's one of the reasons that more of the Constellation work to me is

very exciting. Even if it's putting a piece of boiler plate out on the ocean or doing a drop test on the desert, it's people not doing view graphs. It's people going out with real hands on experience, and then what you can do is start figuring out which engineer is the view graph engineer, which is the engineer that really has the talent. You can't know that *a priori* just looking at grades in classes. You have to have some field experience for them. So it is I think deeply in the government's self interest and NASA's self interest to create opportunities, whether buying small satellites through commercial vendors or giving R and D contracts to universities to build hardware or holding work in house to develop and train a new generation and a new country of people who have some of that humility in front of the hardware and who have some of that touch because without them, we're not going anywhere.