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THE PATH FROM LEO TO MARS

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED TWELFTH CONGRESS

SECOND SESSION

SEPTEMBER 12, 2012

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED TWELFTH CONGRESS

SECOND SESSION

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THE PATH FROM LEO TO MARS

WEDNESDAY, SEPTEMBER 12, 2012

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Committee met, pursuant to notice, at 2:05 p.m. in room SR–253, Russell Senate Office Building, Hon. Bill Nelson, presiding.

OPENING STATEMENT OF HON. BILL NELSON, U.S. SENATOR FROM FLORIDA

Senator NELSON. Good afternoon. I was waiting to see the arrival time of Senator Hutchison. And so what we will do is go ahead and get some of the introductions done so that when she arrives, we will be able to get right into the meat of the hearing.

I want to thank everybody for being here in what is going to be an extraordinary hearing. It is interesting that today is the 50th anniversary of President Kennedy's speech at Rice University where he said, "We choose to go to the Moon." And that bold challenge would be met within 7 years.

And when Neil stepped down from the Lunar Module ladder onto the surface, it was one of the country's proudest and most riveting moments. It was an event that reminded us how triumphs can unite the people of our nation. And indeed, I happened to be a lieutenant at the time abroad, and I saw that unification of the people of planet Earth at that time.

And we reflected on such triumph earlier this summer when *Curiosity* landed on Mars, and we reflected on the ingenuity and talent that is required for those extraordinary achievements a few weeks ago when sadly we heard of Neil Armstrong's passing. And so tomorrow morning at the National Cathedral, the country will bid farewell to one of our most cherished heroes. And it is with his spirit in our hearts and President Kennedy's vision in our minds that we look today at NASA's overall exploration program.

The whole world was captivated by the harrowing landing of the rover. I have seen it. It is as big as a Volkswagen. And we continue to be fascinated by the amazing high definition images that we are getting back from the rover's landing site.

We are fortunate today to have members of *Curiosity's* team here to kick off our hearing with a mission update. We will be briefed by Dr. John Grunsfeld, the Associate Administrator for NASA's Science Mission Directorate; Dr. Fuk Li, the Director for the Mars Exploration Directorate at NASA's JPL; Dr. John Grotzinger, Pro-

fessor of Geology at Caltech and the project scientist for *Curiosity's* mission.

And after that update, we're going to move on to our witness panel, where we will be examining the progress of NASA's exploration program under the NASA authorization bill that was passed in 2010, particularly as it relates to a future human mission to Mars. So our witnesses include Dr. Steven Squyres, the Goldwin Smith Professor of Astronomy at Cornell and Chairman of the NASA Advisory Council; Dr. Charles Kennel, Chair of the National Academies Space Studies Board and Director and distinguished Professor Emeritus at Scripps Institution of Oceanography at the University of California at San Diego; and Mr. Jim Maser, President of Pratt & Whitney Rocketdyne, a company that does a lot of things but specializes in rocket propulsion technologies.

And so I want to welcome all of you here today. Dr. Grunsfeld, would you like to introduce your team?

OPENING REMARKS OF JOHN GRUNSFELD, ASSOCIATE ADMINISTRATOR/ASTRONAUT, SCIENCE MISSION DIRECTORATE, NASA

Dr. GRUNSFELD. Certainly. Let me—I will introduce to my left Dr. Li, and he will work from there. But I just want to make a quick opening comment. First of all, thank you very much, Senator Nelson, for inviting here because this is a spectacular result that we have a successful landing of *Curiosity* on the surface of Mars.

My hopes and dreams for this mission were even just the 7 minutes of terror leading up to a successful landing would be as significant for kids today as Neil Armstrong's landing on the Moon, of America's landing on the Moon, was for me that led me into science and studying math, and eventually to become an astronaut, and now I'm associate administrator at NASA.

Those famous words of President Kennedy said we do things not because they're easy, but because they are hard. And when in the cause of science we challenge our teams to do things that are not only a little bit hard, but things that many would say are impossibly hard, I think that's what brings out the best in scientists, engineers, technicians, and people who are excited about exploration. And I think there is no more qualified team and no more team that is more excited about exploration right now than the team that is driving a Rover on the surface of Mars, the *Curiosity* rover.

And with that, I would like to introduce Dr. Fuk Li, who is the manager of Mars Exploration at the Jet Propulsion Lab.

Senator NELSON. All right. Before I turn to Senator Hutchison, Dr. Li, would you introduce some of your team that is here in the audience?

Dr. LI. Thank you. There are two additional members of the *Curiosity* rover team who are with us besides John and I. Rob Manny here, who he is the chief engineer for the project, and he was responsible for resolving a lot of technical problems we have on the spacecraft and development. And this is Beth Dool, she is the lead of our telecom uplink. When we try to talk to the rover and ask it to do what it's going to do in a certain day, she's always involved.

Senator NELSON. So she is the driver. Thank you.

Let me turn to my colleague. And before I do, let me say that this may well be the last Science and Space hearing for Senator Hutchison because unfortunately she has chosen to retire after a very long and distinguished public service record. I can tell you that I mourn the fact that she is retiring because Kay and I have demonstrated how you pass legislation when it should not be partisan, and where there was no daylight between the two of us.

And thus in the midst of what was tumult back in 2010, we were able to pass the NASA authorization bill unanimously out of the Senate, first unanimously out of this committee. And then with a three-quarters vote out of the House of Representatives at 11 at night on the last night of the session. And so I cannot say enough good things about Kay and her leadership and her passion for America's space program.

So with that, let me turn to you, Senator Hutchison.

STATEMENT OF HON. KAY BAILEY HUTCHISON,
U.S. SENATOR FROM TEXAS

Senator HUTCHISON. Well, thank you very much, Mr. Chairman. And I am so looking forward to hearing from you. I had actually hoped we might have one more hearing because I do want to look toward the future, and I think one of the things that we've been missing here is the protection of the future, not just always going as far as we have to go right now, but making sure that we look to the future.

And when the *Curiosity* landed, I saw for the first time really in a long time that enthusiasm of America just seeing the precision of that long, long trip and the landing. It showed that we really can conquer so much more. And so I wanted to have this hearing. The chairman wanted to have this hearing to highlight what is the future, and maybe we can seek out one more hearing.

But we have been a wonderful partnership in assuring that NASA is not undercut so severely that we cannot keep our preeminence.

And if you would just give me one moment, I want to say that this also is the 50th anniversary of President Kennedy's speech at Rice University, where he laid out more of his wonderful vision. And I would just like to take one little quote from there. He said, "But why some say the Moon? Why choose this as our goal? And they may well ask, why climb the highest mountain? Why 35 years ago fly the Atlantic? Why does Rice play Texas?" And then he goes on to say, "We choose to go to the Moon. We choose to go to the Moon in this decade and do the other things not because they are easy, but because they are hard."

And that inspiration that President Kennedy gave us must be continued, and that is—it has been my goal, and I hope that as we are looking toward that next step, beyond low-Earth orbit, on to other parts of outerspace, including Mars, that you will help us fashion that vision.

So thank you, Mr. Chairman. Thank you for all you do in this regard. And I will end by saying that tomorrow we are going to honor the first man who stepped on the Moon, and I know we both plan to be there because Neil Armstrong stood up last year when he, too, was worried that we might be sacrificing the future for the

present. And as shy as he was about publicity, he took a stand, and that, I think, made a huge difference in the course that we have been able to take.

So with that, I want to hear from our witnesses. Thank you.

Senator NELSON. Dr. Li?

OPENING REMARKS OF FUK LI, PH.D., MARS EXPLORATION DIRECTORATE, NASA JET PROPULSION LABORATORY

Dr. LI. Thank you, Mr. Chairman, for giving us this chance to talk to you and give you a short update on where we with *Curiosity*. But before we do that, I would like to say my deep gratitude for your support that has allowed us to develop, to fly, and to land this rover a little more than a month ago.

The support that we have gotten in the past decade and we are getting now has created three significant capabilities in the Nation. The first is a set of strong Mars scientists. Many of these scientists are working in universities across the Nation, and many of them are working with John in the day-to-day operation of the *Curiosity* rover, telling it where to go and what to do.

The second is to put in the preeminent position for the technological know-how how to land on a different planet. Looking back to the soldier in the Rover that landed in 1997, it was about 20 pounds. Today's *Curiosity* is about 2,000 pounds, the size of a small car. This increasing capability is really unique to America.

Finally, it also put us at the forefront of advanced robotic technologies to allow us to operate a rover millions of miles away from Earth in a Martian environment that is cold. Sometimes we do not know what it is, and sometimes it is unfriendly to us.

So with that, I would like to just go back to the landing night and show a video that is about 2 minutes long, and show you the landing event. We were clearly very excited and wanted to share that excitement one more time.

When *Curiosity* went into the Martian atmosphere, it was enclosed in a capsule to protect it. When it went into the atmosphere, it moved at about 13,000 miles per hour. The kinetic energy of that capsule is roughly equal to several hundreds Formula One race car going around at 200 miles an hour.

The protective shield slowed the capsule down, and this video starts the next day when we started to deploy the parachute. Can I—I am going to start a video. Dr. Li. This is a picture taken by the orbital overhead.

So with that, I would like to turn the time over to Dr. Grotzinger. He is a professor of geology at Caltech and the project scientist that leads the science team for this mission. An early results show—to me they show a lot of promise for future exciting science discovery that can only be made when we are on the surface of Mars and interacting with the material on Mars. John?

OPENING REMARKS OF JOHN GROTZINGER, PH.D., MARS SCIENCE LABORATORY PROJECT SCIENTIST, CALIFORNIA INSTITUTE OF TECHNOLOGY

Dr. GROTZINGER. Thank you, Fuk. Thank you very much, Senator Nelson and Senator Hutchison, for this chance to present some additional science and some fun pictures.

Here is our landing site; you see it way out in space. And you can see a lot of big craters around there. But the one that we chose to go to has a mountain in the middle, Mount Sharp as it is known, named after a pioneering planetary geologist.

And if you go in closer, you can see now Mount Sharp. The area represented by the crater is a little bit larger than the area of the State of Connecticut and a little bit smaller than the State of New Jersey. So it is an enormous area that we have potentially for exploration.

But our goal—you can see the landing ellipse just right here, and then that is the spot that we landed on. And our goal is to do some exploration around in this area for the next month or two, and then begin the long trek that will eventually take us into the foothills and up the flanks of Mount Sharp, where we believe there is evidence for water that has once interacted there and could be the very target we are looking for.

To give you a sense of how bold this goal is, you can see Mount Ranier there, which is smaller than Mount Sharp. Mount Sharp, its elevation is greater than any mountain in the lower 48 States, including Mount Whitney. And you can see it is just a tad lower than the highest mountain in the U.S., Mount McKinley there.

This is looking after we landed, one of our first color images that really gives a sense of just how dramatic the landscape is. This is looking toward the crater rim, not towards Mount Sharp, but the crater rim. And we love this photo because those of us that teach geology out in the West often take students to the Death Valley area. And you look out across toward the mountains, you see a little L.A. smog coming in there, and it just looks really familiar. It just seems like a very comfortable place for us, and we love this landing site.

Here is kind of a fun outreach instrument. We have a laser on board that the public has really enjoyed. They have looked forward to this a lot. It allows us to reach out maybe 10 feet away and zap a rock, and it tells you whether or not it is the right rock to go up and spend some more time doing more detailed work. And, in fact, when we do that, this is what you see. There is a little scale bar here on the right, so it is just a couple of millimeters. And the dot that you see here is less than a millimeter, and if you have felt the laser, if it actually zapped you, it might sort of tickle you a little bit. So that is what actually happens.

But what the rest of the world thinks is happening is this. And, you know, they are just having a great time. The people, if you look on the Internet, they just love this mission, and they are really enjoying it.

This to me is really one of our great moments. This is our first footprints on Mars. You look back to the upper right. This is where the rover landed. These are the one, two, three, four marks made by the thrusters as they impinged on the surface and blew the soil away, and here you see wheel tread marks where they begin. And it tells us about our future on this mission and where we landed successfully. We are not driving away from that place. It might be the last time we ever see it that well, we get further away. But we will never forget this image.

Here we are now looking toward Mount Sharp, which is our ultimate destination. It is a 360 degree panorama, and you can see the same one, two, three, four blast marks there. And the elevation change from this point up to the top of Mount Sharp that is blown up here is on the order of three and a half miles high. So it is a tremendous goal that we are trying to strive toward here in exploring the—at least the base of that mountain.

And when you get up close, this is another one the images. It is my favorite. I believe it is probably the team's favorite image. If you look at the foothills, which are about six miles away, there is a little black rock right here, which is blown up in this box here. That rock, as you sense, the size of the Rover. When we get there one day, we are not going to be able to look back toward it. We see it now, and we imagine our future. What will happen as we blaze a trail going up these valleys and look around the corner.

The team is just filled with wonder, and the people that are following the mission are filled with wonder as we look toward this spectacular area.

And finally, I want to finish with an image that is just 2 days old. We have 17 cameras on this mission, and one of them reaches out from the end of the arm and can look back toward the rover. And the principal investigator who built that camera, Ken Edgid, put a penny on the rover because geologists do this all the time on Earth.

We need a scale, we pull it out of our pocket, we rest it gently on the rock, and we take a picture of it. And this is standard practice for us. But this symbol for us has so much depth to it. It is the great thing that this country has achieved through your support to be able to have this mission succeed and even be able to see this image.

And so I, on behalf of the 406 scientists and all of the engineers, probably 1,000 people currently working on this project, want to thank you for the support.

And the last thing I want to point out is something that history will take note of, is that the year here is 1909. The penny was embedded with the anticipation that we would launch in 2009, and we were not able to. And we hit a lot of obstacles along the way, and we needed support. And it came from you, and it came from NASA, and we are ever so grateful for that because we got where we wanted to be. So thank you.

Senator NELSON. Tell us about when you put the packages together and you send it up there, how long do you say it takes to transmit to Mars?

Dr. LI. Right now it takes about 15 minutes to go one from Earth to Mars and from back.

Senator NELSON. Tell us about how you go about planning what that package of instructions is going to tell the rover.

Dr. LI. OK. Maybe, John, you can describe one day in the life of a rover.

Dr. GROTZINGER. OK. One day in the life of the rover starts with us working on Mars time, and because Mars has a slightly different orbit, it is 24 hours, 39 minutes. We have to adjust every day. So the times team gets jet lagged every day by another 40 minutes.

We get up. The first thing we do is we see the data that arrives from the spacecraft back down to Earth. The science team looks at the data, engineers look at the data. We quickly assess what it is that is there, and then we see if that matches our plans from the previous day about what we would like to do next.

Then we go ahead, and it results in probably about 2 hours of tactical decisionmaking where we come up with a list of observations that we would like the rover to be commanded to do. Then we go through another meeting where those observations are confirmed to actually fit within the block of time, energy, and data that is available as the three resources that restrict our behavior.

And then we go through a process where those activities are all vetted amongst another group of engineers that come on a second shift. And then eventually another, you know, six hours later or so, these are all confirmed, vetted, cleared, and then somebody the button that radiates the command sequence up to the rover.

Senator NELSON. And in your exploration to determine if there was water, what is the process by which you do that? Are you looking for chemical composition of the soil and rocks?

Dr. GROTZINGER. It is a mixture of both analytical chemistry and also observations with the cameras. And through this, we are able to merge these observations together, much like was done on MER with spirit and opportunity. But now when we find something that looks like it was a rock or a soil that formed an aqueous environment, we can dig much deeper into it to begin to really understand whether or not that aqueous environment might also have been an environment that could have supported life had life ever existed on the planet.

Senator NELSON. OK.

Senator HUTCHISON. Just to follow up, we always hear that the most important thing that we could find is that there might be evidence of water, which then might lead to some thought that there was some kind of life.

My question is sort of on the same line as Senator Nelson. If you found something that appeared that it might have been formed with a water or aqueous atmosphere, will you then be able to—what all can you tell? Can you tell how long ago it was? Can you tell is there anything in that that would have—would also indicate life or not, or were the water would have come from. What else can you learn if you think there is a water component?

Dr. GROTZINGER. What we would be able to is with our increased capability on MSL, is we really get a sense for how—what kind of environment it was specifically that the water was pressing it in. Was it there for a long period of time? We'll be able to do that a little bit better than we have in the past. But mostly we get a really good chemical assessment of how not only the water was present, but whether or not the environment could preserve organic compounds, which is very important for as a science community because when you stop short and ask the question about can you ever hope to someday find evidence for life on Mars, you first have to look for the calling cards, at least traces, if you will. We call them chemo fossils, little bits of chemical evidence that suggests this is the kind of place that you should go back to and look in more detail.

And our hope is that if we find such bits of chemical evidence, that it will be quite a rich record. This will be the kind of place you would want to go back to and do sample return, for example. You are going to want to go to progressively higher levels in your analysis.

And this is the way we do it on Earth. You go out to the field. There are lots of different rocks to go look at. You never know kind of which one, but you zoom in on it. And it is an iterative process until you bring something back to the lab, and then finally know that you found something really significant.

Senator HUTCHISON. Will you be able to tell how long ago it became extinct or the water went away?

Dr. GROTZINGER. Yes. We have the benefit of the Apollo astronauts who brought rocks back to Earth from the Moon that calibrated the crater rate. And so kind of apply that to Mars, and so we have a rough sense of how old these rocks are there at the crater. They are probably in excess of 3 billion years, somewhere in between 3 and 4 billion years old.

The harder question is to really ask, if we see evidence for water, how long was that water around for. But we do have an instrument that if things go in our direction—it is a long shot—we might actually be able to date the rock that is there and get a sense for how old that water was there.

Senator HUTCHISON. How fast—you are talking about an area bigger than Connecticut. How fast can the *Curiosity* move so that it can cover the amount of land that you are trying to cover in the time that you have?

Dr. GROTZINGER. This is a great opportunity for me to talk about—just mention briefly how important the Mars program is because it is an iterative process with rovers alternating with orbiters. We have orbiters that make maps of where we think the good stuff is. And so when we picked our landing site, we picked the landing site, and then we were able to move the ellipse down in there, and we moved the ellipse very close to a place that from orbit looked really good.

And, you know, I am conservative by nature as a scientist, and I would like to wait a little bit longer. But I think we are a few hundred meters away from a place we feel pretty comfortable that we are going to be able to show if the Rover was formed in water. And then after we explore that for a while, we are going to take that long drive, and it could take, you know, half a year to 9 months to get to the base of Mount Sharp. But then we have another series of opportunities there.

So I think we have got an exploration portfolio of many different options in there, and we have just had the—a little bit of serendipity. It was not total luck that we wound up in this very special place, but I think we are going to be strong right out of the gates here.

Senator HUTCHISON. And just one last question. Is there a time limit in which the Rover will be effective and the computers all work, or do you have a fairly unlimited amount of time?

Dr. GROTZINGER. Well, we tested the spacecraft to deliver a 2-year mission, and in comparison, MER was built to go in 9 months—sorry, 3 months, and we are going on eight and a half

years. So after 2 years, the warranty wears off, according to the manufacturer. But we are looking forward to a real long mission after that, too, I hope.

Senator HUTCHISON. Oh, good. So it could be years that you will keep roving around and poking.

Dr. GROTZINGER. Yes, we hope so.

Senator HUTCHISON. Good. OK, thank you.

Senator NELSON. As a matter of fact, *Curiosity* can greet the human crew when they land.

You have any opinion as we try to develop the technologies and the life support systems that would take us to Mars in the 2030s? Do we need a sample return mission first?

Dr. GRUNSFELD. John, do you want to take it?

Senator NELSON. Just your opinion.

Dr. GROTZINGER. My opinion.

Senator NELSON. Your opinion.

Dr. GROTZINGER. I think the architecture that the Mars sample program return has laid out in the decadal survey that we as a community fully embraced is the right step to take to get us on the way to putting humans on Mars.

You must have this capability to land something on the surface of Mars and get it back off again. And if the technology demonstration for that human step is to bring back some rocks from a carefully chosen place, we will be all the richer for it.

Senator NELSON. OK. Well, we want to thank you. This is an exciting update. Congratulations again on making the country proud. And seeing you all jump up and down was a delightful sight. Thank you on behalf of a grateful nation.

Let us call up the second panel.

We have Dr. Steven Squyres, who is the Professor of Astronomy at Cornell; Dr. Charles Kennel, Chairman of the Space Studies Board of the National Academies; and Mr. Jim Maser, President of Pratt & Whitney Rocketdyne.

So, Dr. Squyres, we will start with you.

STATEMENT OF STEVEN W. SQUYRES, GOLDWIN SMITH PROFESSOR OF ASTRONOMY, CORNELL UNIVERSITY

Dr. SQUYRES. All right. Well, Senator Nelson, thank you very much for the opportunity to appear here today.

My name is Steve Squyres, and my title is the Goldwin Smith Professor of Astronomy at Cornell University. And I am currently the Chairman of the NASA Advisory Council.

A central focus of the NASA Authorization Act of 2010 was the development of two crucial and highly capable elements of a deep space exploration system: the space launch system and the Orion multipurpose crew vehicle.

NASA's development of both SLS and Orion is well under way, passing crucial milestones, like successful test firings of SLS' J–2X cryogenic upper stage, and the delivery of the first Orion command module to Kennedy Space Center.

And what will these vehicles be used for? President Obama has called for sending humans to an asteroid by 2025, to Mars' orbit by the mid-2030s, and to the surface of Mars subsequently. These

are grand goals, and they are broadly consistent with the goals that were expressed in the 2010 Authorization Act.

I see two possible areas of concern. One is that a "pay as you go" approach can result in slow progress if funding levels are not adequate. There has been no human-rated launch system in NASA's history that has had a flight rate as low as the one that is currently projected for SLS and Orion. And with such a low flight rate, it could be challenging to keep flight teams sharp and mission ready, as well as to maintain program momentum.

Another is that the SLS/Orion combination, of course, was never intended to carry out missions to important destinations beyond low-Earth orbit by itself. Additional vehicles are needed. For example, an asteroid mission requires hardware that is capable of providing crew support in deep space for many months. A lunar surface mission, which also can be a stepping stone to Mars, requires a lunar lander. But there is no funding in NASA's budget to develop such vehicles.

Stated plainly, NASA's budget today is insufficient to carry out the Administration's plan on the stated schedule.

Now SLS and Orion will be highly capable, and their development is progressing very well, but they are only part of the picture. Without the means to develop or acquire the missing pieces of the puzzle, a decade from now NASA will be unable to do much more in deep space than duplicate the success of Apollo 8's historic mission to orbit the Moon more than half a century later.

I agree with the 2010 Authorization Act that, quote, "A long-term objective for human exploration of space should be the eventual international exploration of Mars." In fact, in my view, it should be the long-term objective for human exploration of space.

I also believe that robotic missions should serve as precursors to human exploration, both to collect engineering data and, critically, to lay the scientific foundation on which human exploration will be built.

In the recent National Research Council Planetary Decadal Survey that I chaired, the highest priority flagship mission identified was a Mars rover that would initiate a campaign to return samples from the surface of Mars.

Unfortunately, NASA has been unable to follow this NRC recommendation because of deep proposed cuts in the Fiscal Year 2013 budget for planetary exploration. The mission would have been carried out in partnership with the European Space Agency, but that partnership has not come to fruition because of these cuts. With such deep cuts, the scientific investigation of Mars that should provide the underpinning for future exploration by humans is in jeopardy.

The NASA Authorization Act of 2010 provided the agency with a clear set of goals and priorities. The Administration has also articulated its own vision. And these two sets of guidance are not dramatically different, but together they call for more than the agency can do with the budget that it currently has.

A mismatch between objectives and resources is the reason that a crucial piece is missing from a development of our robust capability for human exploration in deep space. It is also the reason we

have seen deep cuts to a program to explore the very solar system body to which we hope humans will one day be sent.

Now this mismatch could be corrected by making some painful choices—eliminating some of what NASA does to preserve full and adequate funding for other things that it aspires to do. That would, however, require a new and much more narrowly focused national consensus on priorities for NASA.

Alternatively, and much more attractively, the agency's budget could be increased, although I realize that that may be difficult in a constrained budget environment.

One other possible approach would be to broaden NASA's capabilities by forging strong international partnerships, as has been done so successfully for the International Space Station. Right now there is no real plan for international participation in NASA's future human exploration beyond the Earth orbit, and the hope for collaboration with ESA for future robotic Mars mission has been set aside at least temporarily. But international collaboration is the path that could hold some potential, I believe, for bridging the gap between what NASA is being asked to do and what its budget allows it to do.

Thank you.

[The prepared statement of Dr. Squyres follows:]

PREPARED STATEMENT OF STEVEN W. SQUYRES, GOLDWIN SMITH PROFESSOR OF ASTRONOMY, CORNELL UNIVERSITY

Mr. Chairman and Members of the Committee, thank you for the opportunity to appear today. My name is Steven W. Squyres, and my title is Goldwin Smith Professor of Astronomy at Cornell University. I have participated for the past thirty years in a number of NASA solar system exploration missions. Recently I chaired the planetary decadal survey for the National Research Council, and I am currently the Chairman of the NASA Advisory Council.

Moving Beyond Low Earth Orbit

The topic of today's hearing is implementation of the NASA Authorization Act of 2010. In my testimony, I will focus primarily on the elements of that act dealing with extension of human exploration beyond low Earth orbit, with particular emphasis on the eventual exploration of Mars.

A central focus of the 2010 Authorization Act was the development of two crucial elements of a deep space exploration capability: The Space Launch System (SLS), and the Orion multi purpose crew vehicle. In my opinion, NASA has made good progress in both of these programs.

Crucial recent events in the SLS development have included completion of the vehicle's System Requirements and System Definition reviews, as well as successful test firings of the J–2X cryogenic engine for the vehicle's upper stage. In the Orion program, several major milestones in the test program have been passed, including water drop tests, a test of the launch pad abort system, and a series of parachute tests. Importantly, the first Orion command module has been delivered to Kennedy Space Center.

So NASA's development of both SLS and Orion, as called for in the 2010 Authorization Act, is well underway.

What will these vehicles be used for?

In a speech at Kennedy Space Center on April 15, 2010, President Obama outlined his Administration's goals for human exploration of space. He called for sending humans to an asteroid by 2025, to Mars orbit by the mid 2030s, and to the surface of Mars subsequently. These are grand goals, and they are broadly consistent with the goals expressed by the 2010 Authorization Act.

Asteroids are important targets for exploration. Scientifically, asteroids contain clues regarding the formation and earliest evolution of the solar system. Practically, they present both an opportunity and a threat. Mining of asteroids could yield raw materials of enormous value for use in space, simply because they need not be lifted from the Earth's gravity well. And we know that asteroids have impacted the Earth

in the past with devastating effects, and will do so again in the future unless we develop an understanding of these bodies sufficient to prevent such an event.

As for Mars, I feel that sending humans to that planet to with the objective of learning whether life ever took hold there is a goal worthy of a great national space agency. I agree with the 2010 Authorization Act that "A long term objective for human exploration of space should be the eventual international exploration of Mars." In fact, in my view, it should be *the* long-term objective for human exploration of space, whether carried out internationally or by NASA alone.

So I disagree with critics who contend that NASA does not have clear goals for human exploration beyond low Earth orbit. In fact, the goals are quite clear, and they have been articulated without ambiguity. Moreover, two of the key elements for achieving those goals—SLS and Orion—are in development and proceeding well.

But I see two significant problems.

One is that the "pay-as-you-go" approach called for in the 2010 Authorization Act can result in disturbingly slow progress if funding levels are inadequate. The current cost-constrained development schedule for SLS and Orion calls for:

- In 2014, an orbital test flight of an Orion capsule with no crew, to be launched on a Delta 4 Heavy.
- In 2017, a lunar flyby test flight of an Orion capsule with no crew, to be launched on a 70-metric ton SLS.
- In 2021, nine years from now, the first flight of a crew in an Orion capsule, again launched on a 70-metric ton SLS, on some mission to be determined.

Subsequent missions would occur on a pay-as-you-go basis, with a launch roughly every two years.

I believe that the low flight rate currently projected for SLS and Orion is a cause for concern. No human-rated launch system in NASA's history has flown so infrequently. With such a low launch rate it would not just be difficult to maintain program momentum; it would be difficult to keep flight teams sharp and mission-ready.

A more serious concern is that the SLS/Orion combination alone is insufficient to carry out missions to any important destinations beyond low Earth orbit. The Orion capsule can support a crew of four for three weeks, which is far too short a time to conduct a mission to an asteroid. An asteroid mission therefore requires development of another major piece of hardware, capable of providing crew support in deep space for many months. There is no funding in NASA's budget to develop this hardware.

Three weeks is enough time for a mission to the surface of the Moon, which like an asteroid mission could be a reasonable stepping-stone to Mars. But such a mission would require a lunar lander, which again is not in NASA's budget.

So if we truly intend to have a program of human exploration to some destination beyond low Earth orbit, there is a piece of the puzzle missing. SLS and Orion will be highly capable vehicles, and their development is progressing well. But they are only part of the picture. Without some means to develop or acquire the missing piece—either a deep-space habitation module or a lunar lander—a decade from now NASA will be unable to do much more in deep space than duplicate the success of Apollo 8's historic mission to orbit the Moon, more than half a century later.

The Ultimate Goal of Mars

As I noted above, I believe that the ultimate goal of NASA's human exploration program should be Mars. As was done in the days prior to Apollo, robotic missions can and should serve as precursors to human exploration. At Mars, the goal of these missions should be more than to collect engineering data necessary to get humans to the planet and safely back to Earth. It should also, critically, be to lay the scientific foundation on which human exploration will be built. If human exploration of Mars is to be for more than "flags and footprints", the scientific case for this exploration must be compelling and clear.

In the recent planetary decadal survey that I chaired, the highest priority "flagship" mission identified by the National Research Council was a Mars rover mission that would initiate a campaign to return samples from the surface of Mars. This mission would be responsible for characterizing a landing site that has been selected for high science potential, and for collecting, documenting, and packaging samples for return to Earth. The Mars science community, in their inputs to the decadal survey, was emphatic in their view that a sample return mission is the logical next step in Mars exploration. Mars science has reached a level of sophistication that fundamental advances in addressing the most important questions will only come from analysis of returned samples. This mission would also explore a new site and significantly advance our understanding of the geologic history and evolution of Mars, even before the cached samples are returned to Earth. A crucial aspect of the

Mars sample return campaign as originally envisioned was that it would be carried out in partnership with the European Space Agency (ESA), reducing the costs to NASA.

Unfortunately, NASA has been unable to follow this recommendation from the NRC. The reason for this is simple: deep proposed cuts to NASA's F.Y. 2013 budget for Mars exploration prevent it. And in the face of these cuts, the hoped-for partnership with ESA has not come to fruition.

If no commitment to a Mars sample return mission is made in response to the decadal survey recommendations, the result will be highly detrimental to the future of U.S. planetary science. More pragmatically, I fear that an inability to enter into a mutually beneficial partnership with a willing, eager, and highly capable agency like ESA could jeopardize future international partnerships as well. And most importantly, the scientific investigation of Mars that should provide the underpinning for future human exploration will be lost.

Possible Paths Forward

As I look at NASA's response to the Authorization Act of 2010, I cannot escape the conclusion that the agency is being asked to do too much with too little. The act provides the agency with a clear set of goals and priorities. The Administration has provided another set of goals and priorities. These two sets of guidance are not dramatically dissimilar, but taken together they call for more than the agency can do with the budget it has. This mismatch between objectives and resources is the reason that a crucial piece is missing from our development of a robust capability for human exploration of deep space. It is also the reason we have seen deep cuts to a program to explore the very solar system body to which we hope humans will one day be sent.

In such a situation, I can see four possible paths forward. One, of course, is to keep trying to do everything called for with an inadequate budget, running the risk of lengthy delays and a job poorly done. In an undertaking as difficult as human exploration of deep space, that is not a good approach. I urge the Congress to avoid this path.

A second is to make painful choices, eliminating some of what NASA does to preserve full and adequate funding for other things it aspires to do. That could be done, but it would require reaching a national consensus on priorities for space exploration that does not now exist.

A third is to increase the agency's budget, making all the things it being asked to do possible. This path is desirable, but is perhaps unrealistic in a constrained budget environment.

A fourth path is to broaden NASA's capabilities by forging strong international partnerships. This approach has worked well in the past. The Cassini-Huygens mission to Saturn is an example on the scale of a planetary flagship mission, and the International Space Station is an example on the scale of a major agency initiative.

Right now there is no real plan for international participation in NASA's future human exploration beyond low Earth orbit, and the hoped-for collaboration with ESA on future Mars missions has been set aside, at least temporarily. But international collaboration is the path that I believe may hold the greatest potential for bridging the gap between what NASA is being asked to do and what its budget allows it to do.

Senator NELSON. Dr. Kennel?

STATEMENT OF CHARLES F. KENNEL, PH.D., DISTINGUISHED PROFESSOR OF ATMOSPHERIC SCIENCE AND DIRECTOR EMERITUS, SCRIPPS INSTITUTION OF OCEANOGRAPHY, UNIVERSITY OF CALIFORNIA SAN DIEGO AND CHAIR, NRC'S SPACE STUDIES BOARD, DIVISION ON ENGINEERING AND PHYSICAL SCIENCES, NATIONAL RESEARCH COUNCIL, THE NATIONAL ACADEMIES

Dr. KENNEL. OK. Thank you, Mr. Chairman and Senator Hutchison, for the invitation to testify. I have some written remarks I would like—longer written remarks I would like to submit to the record.

My topic today is leadership. Let me start with who I am because I have a comment I would like to make. I am Charlie Kennel. I am

chairman of the Space Studies Board, a professor and director emeritus at the Scripps Institution of Oceanography. And I am proud to say that my predecessor as director, Roger Revelle, was on the platform at Rice University when President Kennedy made his inspiring speech.

I must say that Scripps cannot accept the incredible challenge of playing Rice in football, however. But nonetheless, I think *Curiosity* teaches us that when you set a goal that is extremely difficult to achieve, then NASA will beat the odds.

So I am going to talk about goal setting, clarity of goals, and leadership in space. And I am going to spend most of my time reviewing what our Space Studies Board has done, but I am, of course, going to base a lot of my personal remarks on my experience with 12 years on the NASA Advisory Council, four as chair, and an associate administrator, and on the Augustine commission.

In human spaceflight, I believe the International Space Station guarantees our leadership for a decade, especially if U.S. utilization is strengthened. And there your miraculous act that asked the National Research Council and our Committee on Physics and Biology in Space to lay out a program for space science utilization in our most recent decadal survey. And I promised to report—I am pleased to report some promising developments: that NASA has created a new and independent office for physics and biology in space, they are beginning to work very hard to reconstitute a discipline that was basically destroyed by earlier budget cuts, and they are making progress on a non-governmental organization, a user interface organization. And so I think we can see good progress in that area.

But the question before us now is, what will constitute human spaceflight leadership beyond the coming decade? And as Steve has indicated, there are many factors there, and he has reported on the important direction that you gave to the program that is moving forward.

One piece of direction you gave also to us, and you asked the National Research Council to undertake a study of the goals and core capabilities and future directions of space flight beyond the decade.

Now this is a very complicated study. Scientific and technological, sociological, national security, international relations, even philosophical issues, come into what should the goals of human spaceflight be over the long-term. What kind of goals can we set as a country that will keep NASA and the country coming back to making and attending to the achievements that it intends to make, even though there are budget fluctuations, policy, and administrative changes? Where are the long-lasting goals that can serve the program through mid-century?

And I am pleased to say that a distinguished leadership team for the study—you will be impressed—is about to be announced. We have worked very hard to develop stakeholder and public consultation plans. And in my belief, this is the most potentially innovative study that I have been involved with.

It is also the case that, since so many factors besides science and technology go into studying this goal, we are going to draw on the full resources of the National Research Council in many different areas, endeavor beyond those that the Space Studies Board and the

Aeronautics and Space Engineering Board oversee. But we will be principal supporters of that.

Now in this year, we just—I am now going to move on to leadership in space science, and I will end with some remarks on Mars.

Just this year, we completed a round of decadal surveys and a mid-decadal survey that looks over all of the subjects of space science that NASA deals with. And I think that these recent decadals are going to be the best picture of the contemporary state of American space science that you are going to get in the near future. And, of course, there are many, many, many things that were discussed in careful detail. The community was consulted. Hundreds of white papers came in and so forth. But from all of that, I am just going to extract the leadership elements, the ones that inspire people to work beyond their capabilities and to beat the odds.

So first, here are some of the things we need to do for leadership in astrophysics: stay the course with the James Webb space telescope. Despite all the difficulties, it is still a leadership instrument in astronomy and astrophysics. The scientific rationale for it has developed considerably since 2000 when it was first proposed; it can now do extra solar planets with good capability. If we abandon it now, we risk abandoning world leadership in the entire subject of astrophysics, just as the event with the super conducting super collider did, unfortunately, for American high energy physics.

Next, we have to capitalize on American leadership in the dark energy area. And we need to find a way to get the science done that was proposed by the first priority new mission in our most recent decadal survey, the wide field infrared space telescope. The implementation is less important than achieving the goals of maintaining leadership in dark energy science, which we started, and also to continue the work in exoplanets that it was able to do.

The next area—next two areas, I am going to treat together. They are in some ways very different, but they have something in common. One is heliospheric physics—solar terrestrial physics—and the other is Earth science. And of the many issues that they have separately, they have one in common; that is, that the goals that they set for themselves depend in serious ways on interagency coordination, which is where I believe this committee can play a serious role.

In heliospheric physics, it is on the verge of a very exciting new capability that really predicts space weather and the impacts on spacecraft and ground systems from solar storms. It is on the verge of becoming an operationally useful subject.

At the same time, *Earth Science's* most recent report suggests that *Earth Science* is on the verge of defaulting on the science and applications obligations it has thus far successfully carried, because as we look forward into the future, the number of spacecraft devoted to this area looks like it is going to diminish dramatically.

And in both cases, there needs to be collaboration between NASA, NOAA, the U.S. Geological Surveys, and other agencies in order to set the goals for these programs. And congressional and administrative leadership is required to settle these roles and missions.

Now you have heard this many times: you have got coordination fatigue. How many times have you heard this? But there may be one area where the science community can help you out as you try to figure out the roles and missions of the agencies, whose coordination is essential to these—the success of these projects.

Perhaps we scientists, and technologists, and users could identify key variables and standards of measuring those variables that need to be sustained over the long terms as part of a national commitment. And at that point, maybe the agencies will see more clearly what their role is. But they need to look at these variables not only from their measurement in space, but what requirements will be placed on the ground systems to analyze the data, what standards we will use for exchanging data, and how we decide to preserve the data in long-term archives.

So now as promised, I come back to planetary science. There is very much more to planetary science than Mars, but I am going to focus my remarks on that for the moment.

It is leadership science in its essence. Even landing on a planet is something that most people cannot do. Most countries cannot do it. And as the senator mentioned, we believe that with good luck, our energy source will last, and *Curiosity* is going to return unmatched science for as much as a decade. The scientific community will continue to be very busy.

We did not expect to have to come before you and say this, but the future direction for Mars beyond that, which we once thought was fairly clear and secure, has suddenly become unclear. And this is because of the recent cancellation of two missions that were designed in consonance with a strategy for research that was put into place 15 years ago, of which *Curiosity* is the most recent and most spectacular project, a strategy in which the various assets that we devote to Mars work with one another and reinforce each other, so that the whole is greater than the sum of its parts. You could see it during that landing because they had to move one of the orbiting spacecraft over the landing point to take the picture of the landing that became so spectacular on the 'net.

And now, from my point of view as a scientist, those missions were canceled without a clear explanation that is based in science. And Visions and Voyages, the decadal study that Steve chaired for us, provided a similar guiding principle for the next few decades, just as the strategy of "Follow the Water" led to the sequence of missions that right now is ending in *Curiosity*.

The guiding principle for the next series of missions is sample return. And it really is a guiding principle. If you are going to spend big money on Mars, do not spend it on things that diffuse our focus. Spend it on the ultimate goal, sample return. Now why is sample return important? Because when you bring it back, you can bring the full potential of thousands of laboratories around the world to bear on understanding the place where the astronauts are going to land or the characteristics of it. And we also see, from the Lunar Science Institute, that 50 years from now, those samples will still be used for new science that nobody thought of at the time.

I would like to make a point: sample return is no more a call on present resources than is the goal of a Mars human landing. Both

of them are long-range goals, and they—but they focus the use of resources that we do have on a goal that will eventually add up.

And so to my way of thought, and as a part of the Space Studies Board, the unclear goal—the destruction of a clear or the suspension of a clear goal that was guiding our thinking and making our efforts synergistic, is the most serious outcome. It can be repaired. Perhaps the process of repair is under way right now, but I cannot predict. At the present time, NASA is conducting a serious study of how the human spaceflight enterprise in the Mars science community can collaborate.

Now what is really important from all of this, from my point of view, is that there be a clear set of goals where collaboration enhances the leadership of both areas, and not just identify a few nice to haves where we can work together. It is essential to harmonize two essential goals: sample return—understand the environment on Mars and the possibility of life—two essential goals; and landing on Mars, that both share a commitment to leadership, but are only partially synergistic in implementation.

It is important to get the alignment of these goals right because in the past, the relationships between human science—human spaceflight and the science enterprises has been fraught with difficulty and confusion because of unclear goals. And again, congressional leadership is essential to NASA leadership in this area. And we think that SSB—we hope to be able to have, by taking a look at the NASA report as it comes out and looking at it from the point of view of long-range planning and science, just as the NASA Advisory Council suggested we do.

So at the end of the day, I would think that my whole talk has been devoted to the need for consistency of vision and goals as essential to achieving leadership in space. And you know this. The science and technology community can weather budgetary ups and downs, even policy changes, cancellations, this and that. But wholesale changes in direction are another matter all together; I hope that we have time to repair this situation.

And those are my remarks. Thank you very much.

[The prepared statement of Dr. Kennel follows:]

PREPARED STATEMENT OF CHARLES F. KENNEL, PH.D., DISTINGUISHED PROFESSOR OF ATMOSPHERIC SCIENCE AND DIRECTOR EMERITUS, SCRIPPS INSTITUTION OF OCEANOGRAPHY, UNIVERSITY OF CALIFORNIA SAN DIEGO AND CHAIR, NRC'S SPACE STUDIES BOARD, DIVISION ON ENGINEERING AND PHYSICAL SCIENCES, NATIONAL RESEARCH COUNCIL, THE NATIONAL ACADEMIES

Leadership in Space

Mr. Chairman, Ranking Member Hutchinson, members of the Committee:

I am Charlie Kennel, Chair of the National Research Council's Space Studies Board and a Distinguished Professor of Atmospheric Science and Director Emeritus in the Scripps Institution of Oceanography at the University of California, San Diego (UCSD). The National Research Council (NRC) is the operating arm of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine of the National Academies, chartered by Congress in 1863 to advise the government on matters of science and technology. The Space Studies Board (SSB) was established in 1958 to serve as the focus of the NRC's interests and responsibilities in space science research.

The focus of this hearing is progress in implementing the goals of the 2010 NASA Authorization Act—legislation that is clearly aimed at maintaining U.S. leadership in our exploration of space.

Two recent events remind us how important leadership is. Several weeks ago, America lost the first astronaut ever to land on another world, Neil Armstrong. Neil was respected throughout the space community, not only for his competence and his courage, but also for his modesty. He never failed to say that his success was the Nation's success. He credited it to the creativity of tens of thousands of scientists and engineers in NASA, academia, and industry and to the support of millions of the American people. He saw how an inspiring goal gets a supreme effort from the tens of thousands, and enduring support from the millions.

A little more than a month ago, *Curiosity* landed on Mars, and millions of people around the world shared its "seven minutes of terror" with the thousands who built it. This too was leadership, even though there was no astronaut on board. We are confident that *Curiosity* will carry out state-of-the-art science motivated by a very clear goal—to search for evidence of organic molecules and water, the prerequisites for life. But really, it was the audacity of the landing—the incredible sequence of things never done before that had to come out right—that marked *Curiosity* for leadership. One more time, NASA showed that when it is given something extraordinarily difficult to do, it beats the odds.

Where are NASA's next opportunities for leadership? This is a question that the Space Studies Board and our sister committee the Aeronautics and Space Engineering Board are established to help answer for the Nation. Identifying the opportunities for advancing our knowledge of space through human and robotic exploration is the motivation behind the NRC's studies that the SSB and ASEB oversee.

For nearly 3 years. I served as Associate Administrator of NASA for "Mission to Planet Earth," and 12 years on the NASA Advisory Council, including 4 years as its Chair. In 2009, I served on President Obama's Review of Human Space Flight Plans, the so-called "Augustine Commission", and since 2008 I have chaired the Space Studies Board. The views I will present today, which are my own personal perspectives, are largely informed by the work of the Augustine Commission and the Space Studies Board.

Human Spaceflight

As you know, the 2010 NASA Authorization Act asked the NRC to appoint a committee to undertake a study to review the long-term goals, core capabilities, and direction of U.S. human spaceflight activities and to make recommendations to enable a sustainable U.S. human spaceflight program. Following the transfer of funds from NASA to the NRC, the study commenced on August 1, 2012, and the Committee recruitment process is currently underway and making good progress. Prior to the start of the actual study, a number of activities were carried out under a separate initiation task. Those activities included outreach, collection of research materials, the identification of skillsets, knowledge and perspectives critical to the study, and the broad solicitation of names as well as the review of qualifications for an extensive set of committee candidates. Outreach activities conducted in this period included a discussion session held during the Global Space Exploration Conference in Washington, DC, in which representatives from several international space agencies discussed the perspectives of their citizens and governments on the value, rationale, and future direction of human space exploration.

As recognized by the leadership of the NRC, this study embodies technical, sociological—and even philosophical—issues. The study encompasses both exceptional challenges and exceptional opportunities. Accordingly, the NRC staff who are preparing for this important activity have had an extensive series of wide-ranging discussions across the spectrum of disciplines represented in the National Academies family, as well as with the NASA community, the international community, and with members of the space community.

Once the Committee holds its first meeting, tentatively scheduled for later this year, the Committee will begin to solicit broadly based, but directed, public and stakeholder input to understand better the motivations, goals, and possible evolution of human spaceflight. The next task is to start to identify a set of high-priority enduring questions that describe the rationale for and value of human exploration in a national and international context. The Committee has been charged to provide prioritized recommendations and decision rules that could enable and guide future planning for U.S. human space exploration. The recommendations will describe a high-level strategic approach to ensuring the sustainable pursuit of national goals enabled by human space exploration, answering enduring questions, and delivering value to the Nation. Notwithstanding the considerable challenge this study represents, it is my firm belief that this committee will benefit enormously from the fact that they will have been given 22 months to complete their report, a time period that will allow them to consider carefully the difficult challenge they have been set.

In addition to the many technical studies that NASA and others have produced over the years, the study committee will also benefit from previous work by the NRC in related areas. The NRC study *America's Future in Space: Aligning the Civil Space Program with National Needs* outlines how changes in geopolitical context since the end of the Cold War are affecting the national space program and will be among the reports the new study will consider as it gets started. Our recent report *Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era* is a decadal survey recommending a research portfolio that would ensure that the Nation is ready for the next significant phase of human spaceflight. This report presents an examination of the science and technology that can bring about these achievements—such as a deeper understanding of the role of gravity in the regulation of biological systems, how to control critical fluid behavior in space exploration systems, and research on fire safety and water production in an extraterrestrial environment. The report has two foci: research that enables space exploration and research that is enabled by access to space. This is the scientific research needed to pave the way for the profoundly advanced capabilities we must have in order to make the most ambitious exploration goals not only feasible, but cost effective. The International Space Station (ISS) and its research facilities now provide an unparalleled window of opportunity to make significant and sustained progress on these questions, but this will require a full and vigorous exploitation of the Nation's enormous investment in the space station.

Virtually every NASA success has resulted from technological breakthroughs. Our NRC report *NASA Space Technology Roadmaps and Priorities: Restoring NASA's Technological Edge and Paving the Way for a New Era in Space* identifies the top 10 technical challenges as well as the highest-priority technologies for NASA missions that extend and sustain human activities beyond low Earth orbit, explore the evolution of the solar system and the potential for life elsewhere, and expand our understanding of Earth and the universe in which we live.

Some people have said that NASA relinquished leadership of the human spaceflight enterprise when it retired the space shuttle. In my personal opinion, nothing could be further from the truth. The International Space Station, if nothing else, guarantees U.S. leadership for the rest of the decade, and there are at least three things NASA can do now to ensure leadership after that. The first is to realize the full promise of ISS utilization, building on the foundations of its status as a National Laboratory and by rebuilding the Nation's research program in life and microgravity science, as outlined in the decadal survey report mentioned earlier. Next is to encourage America's new entrepreneurial launch industry, not only to support human spaceflight and to bring down the cost to launch scientific spacecraft, but also to give a boost to an entirely new space economy. Finally, by the end of this decade, NASA has to make a firm start on a long-term program of human exploration beyond low Earth orbit. We should not minimize the challenge. First of all, it means developing a solid base of new technology and a heavy-lift launch vehicle in this decade. That is challenge enough, but human beings will have to survive away from Earth for years; the biomedical and radiation hazards must be faced, and we do not understand how we will deal with these problems. To me, the subtlest challenge of all is to learn how to sustain the enterprise for the decades it will take to accomplish its mission. This means settling on clear, fundamental goals that can endure despite the inevitable ups and downs that occur while they are being achieved.

Many people believe that Mars is the ultimate goal for human exploration, and, indeed, the 2010 Act recognizes that "*A long term objective for human exploration of space should be the eventual international exploration of Mars.*" This fact alone makes it clear that NASA's Mars science and human exploration programs have a powerful mutual interest in working together. The key issue right now is to develop a clear set of goals where collaboration enhances leadership for both science and exploration. Otherwise, a relationship that has been fraught with difficulty in the past could again go awry. Fortunately, I see a new spirit of cooperation, and there is reason to be optimistic. That said, it is clear that NASA's space science program is under considerable stress. The past year has witnessed, for example, the disruption, if not outright abandonment of, scientific strategies that have been constructed over many years for the future exploration of Mars and outer planetary bodies such as Europa. And, in the process, international agreements highly advantageous to the research community, NASA, and the Nation were set aside.

Space Science

The 2010 Act instructs NASA to take into account the current NRC decadal surveys when submitting the President's budget request to the Congress. So let me spend a little time reflecting on the current situation there.

The recently completed NRC decadal surveys and related studies, taken together, provide an up-to-date overview of the state of American space science. The study teams sought the views of their disciplinary communities by soliciting hundreds of white papers and conducting dozens of town hall meetings. The decadal survey teams included experienced managers and engineers, as well as scientists, and made independent estimates of cost and technical risk so as to make financially responsible recommendations. In all cases, however, the process started with identifying the most important scientific goals for the coming decade. Some of the financial assumptions may have been overtaken by the recent budgetary turmoil, but the goals behind the specifics still shine through. It is these I relate here, especially those whose achievement is critical to leadership in the coming decades.

American leadership in space astronomy and astrophysics is solid, but not unchallenged. The Hubble Space Telescope, the Nobel-winning Cosmic Background Explorer, and 20 years of systematically planned missions to study the sky in every accessible wavelength range, from microwaves to gamma rays, have kept research in these fields on the forefront. This leadership is ours to lose. First and foremost, we must stay the course and complete the James Webb Space Telescope (JWST). I think neither the scientific community nor Congress knew how challenging (and expensive) this mission would become, but stopping now would have serious consequences for the whole field. Many of us recall that the U.S. lost leadership in particle physics to Europe when the Superconducting Supercollider was cancelled. We cannot let the same thing happen to JWST, which will do in the 21st century what Hubble did in the 20th. Next, we should capture the benefits of pioneering American breakthroughs in dark energy by accomplishing the goals of the Wide-Field Infrared Survey Telescope (WFIRST), the first priority mission in the NRC decadal survey *New Worlds, New Horizons* and a highly capable mission that has an equally compelling science goal in the discovery of extrasolar planets. Completion of JWST may delay their accomplishment, but if we do not pursue these goals in as timely a manner as possible, we lose our edge. Europe will launch a dark energy mission in this decade.

Heliospheric physics, the field in which I started my career, is the most mature branch of space science. In the past 20 years it has achieved a precision of measurement and modeling that astounds me and puts the field on the threshold of transformative advances in its understanding and prediction of "space weather." We now can predict in detail when and how events on the Sun will affect the operation of technological systems that are sensitive to Earth's electromagnetic environment, like electrical power-grids, pipelines, and communication satellites. Congress has a delicate role to play here, as it guides the evolution of this new research-intensive operational program, since relationships among NASA, NOAA, and DOD need to be shaped. Leadership in science does not always mean big missions, it can also mean innovation in program design and integration. Here the SSB's most recent decadal survey, *Solar and Space Physics: A Science for a Technological Society,* excels. Its DRIVE (Diversify, Realize, Integrate, Venture, Educate) initiative proposes a mix of orbital and sub-orbital missions, modeling, and ground-based measurements that is both scientifically innovative and fiscally realistic. Later in the decade a set of moderate missions will enable a set of compelling science targets that the survey identifies as key to advancing our understanding of the complex system that encompass the interactions of the Sun with our home on Earth, its planetary environs, and the surrounding heliosphere—the outer edges of which are being explored now by the Voyager spacecraft 35 years after their launch.

Earth science, the field in which I was once NASA's Associate Administrator, staked out a position of undeniable leadership in the 1990s that could be lost in the next decade unless some firm directions are set. Twenty years ago NASA began the Earth Observing System, a project comparable in scope and ambition to JWST and *Curiosity.* This project was manifestly important to society, and it was based on a new conceptual synthesis, the first comprehensive approach to understanding the behavior of Earth as a system. Now, 20 years later, the SSB's recent *Earth Science and Applications from Space: A Midterm Assessment of NASA's Implementation of the Decadal Survey* documented a crisis in Earth observations. We are now at the point where even optimistic scenarios of future capabilities predict that the number of missions and instruments to observe Earth from space in the next decade will fall precipitously unless existing space assets remain operational well beyond what is anticipated. Many contributing factors are documented in the report, but, in the end, the fact is that a cornerstone of NASA science, *despite good management of the resources it has,* is neither living up to its promise nor fulfilling national needs.

NASA cannot solve the crisis in Earth observations by itself, although without NASA the enterprise fails. In this field, NASA needs to take a national approach, and it has to make complex and fragile arrangements with other U.S. agencies and

international partners. Indeed, several recent NRC reports, including the decadal survey and the midterm assessment, have highlighted the need for a comprehensive national strategy for Earth observations from space to better address a plethora of problems that center on the misalignment of agency roles and responsibilities with agency budgets. Above all, the Earth observation enterprise needs the country to agree on a stable, motivating vision like those that keep astronomers and physicists returning to the same questions for decades until they get answered.

Planetary science is leadership science in its essence. Simply getting to another planet is a major challenge, and landing on one is where the United States is a complete master, as *Curiosity* shows; the U.S. is also the undisputed, but not unchallenged, leader in the orbital exploration of the outer planets and their satellites. My colleague Steve Squyres can make these points with much more authority than I, since he chaired *Vision and Voyages,* SSB's recent decadal survey in planetary science. Here I restrict myself to a few general remarks. His committee's report identifies the highest-priority mission being one that would begin the process of returning samples from Mars. The report emphasizes the importance of maintaining a balanced program and describes promising smaller missions and the supporting activities necessary to make these programs successful with strong support for the New Frontiers and Discover classes of missions. Many people have praised *Vision and Voyages* for its succinct set of "decision rules" designed to help cope with changing budgetary circumstances.

Curiosity, because it has a long-lasting nuclear power source, could produce world-class science throughout the coming decade, but unfortunately there is now a question of what comes after that for Mars. *Curiosity* is the product of a program strategy developed in the late 1990s to answer a first-class scientific question: What did water on Mars do in the past, and where is it now, and is there evidence for organic molecules? (Water and organic molecules were, after all, the prerequisites for life on Earth). Recently, the next two missions consistent with this strategy—The Mars Trace Gas Orbiter and the Mars Astrobiology Explorer-Cacher—were cancelled; whatever the issues of risk and financial prudence that might have motivated this decision, it sends a chill through the Mars science community and its many followers in the public. The near future looks bright, but what will come after the launch of MAVEN [1] in 2013 and InSight [2] in 2016? Will we be able to keep the team together? Fortunately, *Visions and Voyages* points to a guiding direction for Mars science exploration. Missions should contribute to the goal of sample return, so that one day hundreds of scientific laboratories on Earth can be put to work broadening the scientific beachhead our landers are occupying.

NASA has assembled an internal team to identify an integrated strategy for the agency's Mars Exploration Program in light of current funding constraints. NASA has said that team's initial focus will be on a possible 2018–2020 robotic mission as part of a program whose framework will be developed in consultation with the science community and international partners, and which aims to advance the priorities in the *Vision and Voyages* decadal survey. This team's report is expected to be released soon, and we at the SSB with our Committee on Astrobiology and Planetary Science stand ready to assist in ensuring that the eventual program pursues the carefully developed priorities of the decadal survey—priorities that are the result of a 2-year process that represents the consensus position of the scientific community on a balanced planetary science program that will produce, as Steve Squyres has said many times, the best science return per dollar for the Nation.

I have highlighted where I see opportunities for leadership in each of NASA's main areas of space endeavor. I have had to gloss over the many other less visible, but in total equally essential, activities that contribute to excellence. These may be found in the reports themselves. But there is one more requirement for leadership that can be found in every report: *balance.* Balance means different things in each area, but basically it means that we should not put all our eggs in one basket. Also, balance definitely does not mean "something for everybody!" Smaller spacecraft missions, sub-orbital flights, modeling, data analysis, and research grants sustain the quality of the disciplines that originate the great leadership projects. It is striking to me that each of our committees put its recommendation for balance on an equal footing with its first-priority leadership mission.

What does this mean for you as legislators? Keep in mind that when you support leadership projects, you are investing in the spirit of innovation, and when you support balance, you are investing in the capacity to innovate.

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[1] Mars Atmosphere and Volatile Evolution, the second and final Mars Scout mission.

[2] Interior Exploration using Seismic Investigations, Geodesy and Heat Transport, the next Discovery mission.

Never before has congressional leadership been more critical to America's leadership in space than now. Now is the time for you to shape enduring goals that can guide America's space program to its next stage of leadership in the complex times you see ahead. The space science and technology community can deal with budgetary turbulence, but only when there is a stable sense of direction.

Senator NELSON. Thank you, Dr. Kennel.
Mr. Maser?

STATEMENT OF JIM MASER, PRESIDENT, PRATT & WHITNEY ROCKETDYNE

Mr. MASER. Thank you. Senator Nelson, Senator Hutchison, thank you for the opportunity to testify on this important topic.

I would like to start by recognizing Senator Hutchison for her decades of public service. You have been a fearless and long-time champion in particular of education reform, which I think is the first and most critical element to preserving the future of our space program going forward. And you have been a true leader for the state of Texas and for the nation. I wish to thank you for your dedicated service and wish you well on your retirement.

For the purpose of today's discussion, I want to highlight these major themes and concerns. First, the need to create an enduring vision, one that will focus on increasing scope and reach of presence through continuous and incremental steps; the need for a consistent, clearly articulated budget that allows the execution of an enduring vision; recognize that it is NASA's job to define how to execute an enduring vision within the budget they have been given; and finally, to reinforce that the Congress and the Administration have decided that SLS is a beyond Earth orbit vehicle of choice, and everyone's focus needs to be on progress that will lead to exploration and the fulfillment of this enduring vision, an exploration of vision that will push the boundaries of innovation. It is my belief that is what the 2010 NASA Authorization did when it laid out the need for NASA to move forward with the space launch vehicle and the Orion crew capsule.

For some time now, and especially since the end of the space shuttle program, NASA has seemingly suffered from a lack of an overarching, enduring vision for leadership in space science technology and exploration. The Administration canceled Constellation, and then established new priorities and direction, such as landing on an asteroid and funding commercial space capability consisting of multiple providers without clearly identifying a supporting or marketer demand beyond the U.S. Government itself. This was done with what appears to be limited coordination and consent from Congress.

Because of this lack of coordination, Congress has been compelled to be prescriptive in its legislative language with regard to NASA's specific systems architectures and requirements to ensure at least some level of stability for the industrial base and preservation of unique and critical skills.

I believe in order for any of the discourse we are talking about today to be relevant, we must have an enduring stable vision for NASA that is set by the President in alignment with Congress and budgets in a consistent manner that enables execution over time-

frames that extend beyond a single administration or congressional election cycle.

When our nation first embarked upon space exploration leadership, the expectation was that we would incrementally and continuously expand our scope and reach of presence over time, both robotically and with humans. As Jay Barbree said in his recent five-part commentary, "We must have an affordable science-driven method of learning, moving steadily outward in logical increments." I believe we must have clear missions and destinations. And then identify the capabilities that either already exist or need to be created in order to complete these missions. It is really that simple.

There is no one right solution to how NASA can achieve this incremental exploration and fulfill their charter. Someone must choose, and we have a nation—as a nation have created NASA to do just that. As such, NASA has determined they need a heavy lift launch capability and space launch system as the answer to that need.

The Augustine Commission in their review of the NASA human spaceflight program made the following statement: "The committee reviewed the issue of whether exploration beyond lower Earth orbit will require a super heavy lift launch vehicle, and concluded that it will." Regardless of the exact mission architecture that is ultimately pursued, or the exact heavy mass requirement, the heavy lift launch capability that the SLS will provide is fundamental to its execution, and must be pursued with the utmost priority and speed.

NASA's entire exploration architecture is dependent upon its capabilities as an enabler. And now that an architecture has been established, it is imperative that it receive adequate funding and in no way follows the fate of the Constellation program.

What NASA cannot afford to do is continue the trend of canceled programs, re-baselining, and seemingly random directional changes of objectives and priorities. These fits and starts have cost this Nation considerable effort, time, and money, with tremendous disruption, loss of critical skills, and little return or progress.

Clearly SLS will be most capable with a U.S. launch vehicle and with the Orion spacecraft and modern systems, will enable new missions of human exploration across the solar system, as well as benefit high priority science missions. It leverages and builds upon past experience and technology.

This is the time to ensure we get beyond Earth orbit as fast as possible, as cost effectively as possible, and safely as possible. Once we do that, we can resume true exploration in the innovations and inventions necessary to push the boundaries and explore and live on other bodies.

And in order to push the boundaries, both robotic and human exploration missions have their place within an overall exploration program. There has been a lot of talk about returning to the Moon. SLS gives NASA the flexibility to do that, perhaps first launching robotic missions and then humans.

A continual incremental approach to exploration should be the norm. While humans explore the poles of the Moon, robots should be characterizing the environments on Mars and its moons. When

humans finally explore the Martian system, robots can be exploring the icy depths of the vast oceans of Jupiter's moon, Europa.

We must recognize there is no end to this process, no victory dance followed by the abandonment of vital innovation engine for the country—just simply continuous progress.

The enormously successful landing of the Mars science lab, *Curiosity,* is a perfect illustration of another step in this incremental development and exploration, as well as the complementary use of precursor robotic missions in space exploration.

I want to stress that NASA's exploration programs are not simply intended to return scientific data. They lead to technologies that can be used and built here on Earth, and most notably, they inspire our nation and future generations to come.

Finally, like many other people today, on the 50th anniversary of the Rice speech, I have a quote from John F. Kennedy that I use often, and it is a little bit longer of the version you used: "We choose to go to the Moon in this decade and do the other things, not because they're easy, but because they're hard, because that will serve to organize and measure the best of our energies and skills." And I say that because I'm not nostalgic for the days of the past, and I don't want to relive the glory days, but because President Kennedy said doing the hard thing drives us to use the best of our energy and skills, which in turn creates the need and motivation to expand our boundaries. NASA's job is to do the hard stuff, constantly pushing the boundaries that requires technological advancement.

We grow as a nation because it takes the best of our people and capabilities to push the limits of creativity and abilities leading to true innovation and true inspiration. As such, innovation and inspiration cannot be goals of what NASA does and strives for, but rather is the result.

Just as *Curiosity's* mission spawned innovation, which inspires us all, sustained human exploration will challenge us to future innovations that we cannot even predict. But know from experience will keep us in a leadership position, not only in space, but here on Earth.

Thank you for the opportunity to address the Committee today, and I look forward to any questions you have.

[The prepared statement of Mr. Maser follows:]

PREPARED STATEMENT OF JIM MASER, PRESIDENT, PRATT & WHITNEY ROCKETDYNE

Chairman Nelson, Senator Hutchison, Senator Rockefeller and distinguished members of the Committee:

Thank you for the opportunity to testify on the important topic of NASA's path from LEO to Mars and their progress and challenges in developing a human spaceflight and exploration capability under the NASA Authorization Act of 2010.

Before I begin, I'd like to start by recognizing Senator Hutchison for her decades of public service. She has been a fearless and longtime champion of education and education reform which is probably the first and most critical element of preserving the future of our Nation's space program. As the first woman elected to the U.S. Senate from Texas, she has served as a role model and an inspiration to others. She has been a true leader for the state of Texas and for our Nation, and I wish to thank you Senator Hutchison for your dedicated service and wish you well in your retirement.

I think it's important as a foundation for this discussion to touch on the issue of NASA's strategic direction. For some time now and especially since the end of the

Space Shuttle program, NASA has seemingly suffered from a lack of an overarching, enduring vision for leadership in space science, technology exploration. The Administration cancelled Constellation and the Moon mission and and established new priorities and directions such as landing on an asteroid and funding a commercial space capability. This was done with what appears to be limited coordination and consent from Congress. Congress, being concerned and not necessarily in full agreement with these Administration decisions, has been compelled to be prescriptive in its legislative language with regard to NASA specific systems architectural requirements to ensure some stability in the industrial base and preservation of critical and unique skills. .

Without clear direction from the Administration, NASA has been left to juggle a multitude of tasks. NASA is very busy trying to reestablish U.S. access to the International Space Station and maximize its scientific returns and develop a Beyond Earth Orbit (BEO) launch system with no clear set of missions. NASA is working all of those efforts in conjunction with trying to develop human and robotic roadmaps with its international partners, fund a commercial space enterprise to sustain multiple competitors without clearly identifying a supporting market or demand, and accomplish meaningful results in a timely manner. Finally, they are attempting to do the many other things that keep ten NASA Centers healthy. NASA is being asked to do all of this with a flat, essentially declining budget.

As a result of these influences, NASA is left trying to fit all these priorities into a cohesive story in the face of extreme budget austerity and more political sea changes on the horizon. They are trying to consolidate and communicate a vision to fit the direction and restrictions provided by the Administration and Congress rather than executing on their original charter to explore, push the boundaries and limits of our knowledge and capabilities, serve as the leader in space technology for the rest of the world, and finally, and perhaps most importantly to inspire our Nation and the world.

The Administration and Congress must reach agreement on a path forward as budgets are established rather than the current practice of the Administration putting out an entirely new direction in an uncoordinated budget, only to have Congress stall over the non sequitur funding proposals. Senators Nelson and Hutchison had to intervene last time to establish a direction and reach a plan acceptable to all, but not before a year of wasted time and uncertainty. This cannot happen again.

An enduring, stable vision for NASA should be set by the President and supported in Congress in a consistent manner that enables execution over timeframes that extend beyond a single Administration or Congressional election cycle. Budgets should be provided that are consistent with executing the direction and are stable over the timeframes required to execute the direction. It is NASA's job to define the manner in which to achieve the vision and then execute on the vision within the budget. An enduring vision for NASA should be more focused to better align with the current constrained budget environment, and the vision should be mission-driven. A focused, mission-driven vision that endures will allow NASA to maximize the returns to the American people for the resources provided. Finally, the vision should push to accomplish feats never before achieved by mankind.

What NASA cannot afford to do is continue the trend of cancelled programs, rebaselining and seemingly random directional changes of objectives and priorities. These fits and starts have cost this Nation considerable effort, time and money with tremendous disruption and with minimal return.

Maximizing the value returned from the budget provided means that NASA needs to examine how it can right-size its resources and infrastructure to efficiently execute a more focused mission. Preserving every capability NASA has acquired is simply not possible in a constrained budget environment. NASA itself must retool it's infrastructure to become a "built to last" organization that doesn't sink huge amounts of money into standing monuments that don't have the ability to adapt to future missions, large staffs that are sized to be all things to all people, and a large bureaucratic management structure that is unable to move with speed and agility. While the government is the only method to continue this long-term exploration initiative, it must not be immune to the known precepts of efficient and lean management so that the dollars being spent yield the most possible learning. Priorities must be chosen and decisions must be made on what capabilities should no longer be supported and what capabilities must be retained to accomplish the vision. We have created NASA to define the best way to achieve the vision with the budget available, not to be everything to all people.

When our Nation first embarked on space exploration and leadership, the expectation was that we would incrementally and continuously expand the scope and reach of our presence over time—both robotically and with humans. As Jay Barbree said in his recent 5-part commentary, we must have "an affordable, science-driven meth-

od of learning, moving steadily outward in logical increments." We must have clear missions and destinations—and then identify the capabilities that either already exist or need to be created in order to complete these missions. It's that simple.

There is no one right solution to how NASA can achieve this incremental exploration and fulfill their charter—someone must choose and we as a nation have created NASA to do just that.

NASA has determined that they need a heavy lift launch capability, and Space Launch System is the answer to that need. The Augustine Commission, in their review of NASA's Human Spaceflight Program, made the following statement: *"The Committee reviewed the issue of whether exploration beyond low-Earth orbit will require a "super heavy-lift" launch vehicle, and concluded that it will."* Regardless of the exact mission architecture that is ultimately pursued, the heavy-lift launch capability that the SLS will provide is fundamental to its execution and must be pursued with utmost priority and speed. NASA's entire Exploration architecture is dependent upon its capabilities.

SLS will be the most capable U.S. launch vehicle and, with the Orion spacecraft and modern ground systems, will enable new missions of human exploration across the solar system, as well as benefit high-priority science missions. It leverages and builds upon past experience and technology. Now that an architecture has been established, it is imperative that it receive adequate funding and, in no way, follows the fate of the Constellation program. We have clearly seen the negative impact of inaction and indecision after the end of the Space Shuttle program: loss of momentum and direction, wasting precious financial resources, and a significant loss of critical space industrial base skills.

The objective is to establish a heavy lift capability. We know how to do that reliably now, this is not the time to once again baseline new technology, of which little has really been identified anyway. This is the time to ensure we get beyond Earth orbit as fast as possible, as cost effectively as possible, and as safely as possible. Once we do that, then we can resume true exploration and the innovations and inventions necessary to push the boundaries and explore and live on other bodies.

There has been a lot of talk about returning to the Moon, and SLS gives NASA the flexibility to do that, perhaps first sending robots, then humans. A continual incremental approach to exploration should be the norm. While humans explore the poles of the Moon, robots should be characterizing the environments on Mars and its moons. When humans finally explore the Martian system, robots can be exploring the icy depths of the vast oceans of Jupiter's moon Europa. We must recognize there is no end to this process, no victory dance followed by the abandonment of a vital innovation engine for the country.

The hugely successful landing of the Mars Science Lab Rover Curiosity is the perfect illustration of this incremental development and exploration as well as the complimentary use of robots in space exploration. Curiosity will continue to rove around Mars in the months ahead potentially paving the way for humans, and SLS will be key to that incremental strategy for exploration.

Both robotic and human exploration have their place within an overall space exploration program. Robotic exploration must lead human exploration in order to truly understand what technological problems have to be solved and which can rely on existing technology. While the use of humans for exploration might not yield the same marginal return in scientific data for the investment, the returns on technological innovation that benefit society are. NASA's exploration programs are not simply intended to return scientific data. The technologies developed to acquire the scientific data often represent even more valuable returns. These technologies are integrated into the capabilities of the U.S. companies that participate in NASA programs and increase their productivity and global competitiveness. Successfully placing humans into the harsh, unexplored environments associated with space exploration results in benefits to people back on Earth in ways that cannot be equaled by placing a robot into the same environment. These benefits include everyday technologies such as ear thermometers, heart rate monitors and fire retardant materials to computer microchips, plasma displays and aircraft collision avoidance systems.

More intangible, but equally important, exploration is inspirational to the United States. And in this context, the returns from human exploration are far greater than robotic exploration.

So it is clear, first and foremost, that NASA must be provided with an enduring and stable vision that can and will survive any unilateral attempts to jerk the wheel around as we pass through Administrations and Congresses. Once this vision is established we need to let NASA do their job. The Agency is uniquely qualified to organize and integrate the diverse and often biased inputs from industry, academic and scientific communities, international community, etc—and look at options, es-

tablish a direction and plan of execution consistent with vision and budget, and then actually execute it.

NASA must also return to being a mission-driven organization. Technology and capability development without a clear mission use is misguided and generally inefficient in the same way that hammer and nail is useless without something to build. A clear mission provides alignment to all stakeholders and allows the most efficient use of scarce resources. NASA did not build the vehicles and technology needed to land on the Moon and then decide to go. The Nation, through the Administration and Congress, gave NASA a goal of landing on the Moon and NASA figured out how to do it. NASA did not build the space shuttle knowing what all 135 missions would entail. They knew they needed the capability to transport people and large payloads to build an international space station. We must return to that model.

Finally, I'd like to close with a quote from President John F. Kennedy's 1962 speech at Rice University. I'm sure most of you know the quote by heart. He said, "We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills." I don't use this quote because I think we should live in the past or because I believe we should be reliving those glory days. I use it because as President Kennedy said doing "the hard things" drives us to use the best of our energies and skills, which in turn creates the need and motivation to expand our boundaries. NASA's job is to do the hard stuff—constantly pushing the boundaries. We grow as a nation because it takes the best of our people and capabilities push the limits of our creativity and abilities leading to true innovation and inspiration. As such, Innovation and Inspiration cannot be goals of what NASA does and strives to do, but rather the result. Just as Curiosity's mission spawned innovation which inspires us all, sustained human exploration enabled by SLS and Orion will challenge us to future innovations we cannot even predict, but know from experience will keep us in a leadership position not only in space, but especially on Earth.

Thank you again for the opportunity to address the Committee today. I look forward to responding to any questions you may have.

Senator NELSON. Well, thank you all. All right. We are developing a rocket called the Space Launch System. We are developing a human capsule called Orion. All of this is happening while the average American thinks that the space program is over because they have attached the visible evidences of the space program naturally to the Space Shuttle over the course of three decades. And when the Space Shuttle was retired, that naturally leads people to the conclusion that it is over.

And now we are ramping up this whole new system to get us out of low-Earth orbit. When Apollo was developed, other than the goal of getting to the Moon and back, it was also then utilized for other things, a thaw in the Cold War in the rendezvous and docking of a Soviet spacecraft and an American spacecraft, which was the forerunner to bringing all of this cooperation that we now share with Russia and our many international partners on the International Space Station.

So my question to you all is, as we develop the SLS and Orion, what do you see as the full potential of that system? Mr. Maser, let us start with you. What would be some examples of the types of mission that the SLS and Orion would make possible?

Mr. MASER. Well, certainly first and foremost is getting back beyond Earth—lower Earth orbit again. We have not been there in a very long time, and this will enable us to do that first and foremost, and start to try out and test all the new technologies that have developed and evolved since we have last been there. And also to leverage at least some of the—and you guys can speak to it better than I could—some of the human science that has been going on on the space station as we get out beyond for an extended period

of time in the radiation environment and in other environments. I think initially that is what at first enables.

There are a number of missions—I know asteroids have been brought up as a potential one. We have not identified one yet, and it looks like it is going to be a hard one to get to. So I think we need some fallback plans. And I know there are some discussions going on about other interesting points where there is gravitational equilibrium between various bodies where we could spend extended durations of time, some space, longer than we have ever spent before beyond lower Earth orbit, and learn more about how the human body reacts.

I personally believe, though, to get us to full fruition, there is a lot about what Dr. Squyres talked about, is eventually we are going to need a lander. And eventually I think we need a series of missions that are incrementally more difficult. So you can just see there is a general pattern here that I think makes a lot of sense, is you have robotic precursor missions. Then you learn to live off the planet, whether it is in space first for a period of time, eventually on the Moon for a period of time. And once you have learned how to live off the planet, somewhere that is not too far away, then you can start moving to places further away that have been doing robotic exploration.

But it never ends, and I think that is a point I was trying to make in my comments. It is not this—because you hear comments about we do not any more flag planting missions. It is not about one giant mission, you achieve a hurrah, and then you wonder what is next. You always know what is next. You are always working on it, and it is stable and predictable, and everybody knows what technology we need to achieve that.

Senator NELSON. Just like we did in Apollo, which was an incremental mission, starting with Mercury, Gemini, Apollo, in an environment that we did not know anything about.

Mr. MASER. Exactly.

Senator NELSON. And eventually we went there. Let me ask Dr. Kennel, give us some examples of the types of science missions that would be enabled by either crewed or unmanned launches of the Space Launch System.

Dr. KENNEL. Beyond low-Earth orbit.

Senator NELSON. Yes.

Dr. KENNEL. There are several. We have already had some precursor missions, for example, robotic sample returns from asteroids, which will give you some idea of the chemistry. There are lots of good asteroids.

There is a distant, but important security goal that can be achieved by approaching an asteroid with a system of significant mass. It is known, for example, that from time to time, asteroids have hit the Earth—one 65 million years ago destroyed the environment for the dinosaurs. And if we are going to live for a long time as a civilization, you have to worry about Earth crossing asteroids.

And it turns out that you can predict maybe 10 or 20 passages before they actually hit the Earth when they are going to—and send a spacecraft there. You do not even have to nudge it; mutual gravity will move it out of its orbit. The proof of principle would

be very useful, and you could get that done while you are doing some science. I think that the main argument for human beings has always been they are very good geologists. They can take a look at what they see and tell you in ways that an automated laboratory cannot.

And so I think that the picture that I would have, and this is not in anybody's decadal report is: go to Mars. You want to go there? Go there. Missions of increasing sophistication. You might as well set a tough goal of sample return because that tests all the technologies for both landing and takeoff. The sample return gives you deep scientific knowledge. You might even have a couple of them to characterize the most reliable knowledge where you are going to land, and you go.

Senator NELSON. And congratulations to the *Curiosity* crew——

Dr. KENNEL. Yes, indeed.

Senator NELSON.—that indeed you are part of the forerunner of the first number of steps.

And, Dr. Squyres, tell us what types of planetary science missions does the unique capability of the Space Launch System, this new big rocket that is evolvable in size, what does that provide?

Dr. SQUYRES. Well, like Dr. Kennel, I am excited by what we can do at an asteroid. I was recently part of a four-member NASA crew—I was the one non-astronaut on the crew—that conducted a 2-week long mission at the Aquarius Laboratory in your home state of Florida, simulating the kinds of EVA, extra vehicular activity, tools, and equipment that one would use for exploration of an asteroid. And it got me very excited about what a human crew—a crew of human scientists, explorers, could do at an asteroid—on a mission that would be enabled by SLS.

I think most importantly, heavy lift capability is essential for someday sending humans to Mars. I am a big fan of robotic exploration. I am a member of the science team for the *Curiosity* mission. But what our magnificent state-of-the-art *Curiosity* Rover can do in a day, you could do in about 45 seconds. And what our magnificent Opportunity Rover has done on Mars in eight and a half years, you could do in a good week, week and a half, something like that.

So what humans can do in the way of science on the surface of Mars far surpasses what can ever be done, in my view, by these wonderful rovers that I have and so many of us here have devoted our careers to building and operating.

So I see SLS heavy lift and the ability to get humans beyond low-Earth orbit as fundamental to some of the most important planetary science that we have ahead of us.

Senator NELSON. Senator Hutchison? And I might say that Senator Hutchison was key as we worked through the design of that NASA authorization bill to make the system evolvable, so that it starts out what we have the funds and the capability for now, but it can grow to whatever the needs of the mission are.

Senator HUTCHISON. Well, thank you. That was certainly a joint effort, and the purpose was to have the technology in the shuttle that is going to go to and from the space station that would be transferable to the heavy launch vehicle with Orion, so that we

maximize efficiency with our taxpayer dollars. And that was—that is what we have worked very hard to assure that NASA will do.

When we talk about the importance of the robots and how exciting *Curiosity* is, nevertheless, *Curiosity* cannot come back with the samples. Is that only going to be able to be done when we can put humans there that can return or are we looking at another technology feat that would be an end run of trying to get the robot down and bring samples back?

Dr. SQUYRES. Sample return can be conducted robotically, and indeed the mission that was recommended in the recent planetary decadal survey as the highest priority would have been the first step in a set of missions that would have robotically returned samples from Mars.

Now returning samples from Mars is in no way a substitute for the magnificent science that can be done by actually sending humans there. But what it does is it lays the scientific groundwork. It enables us to design a program of future human exploration of Mars that is driven, that is motivated, that is informed by the scientific results that come from those returned samples, and gives the taxpayer the maximum return on the substantial investment that would be involved in sending humans to Mars.

So we can bring samples back robotically. It is also possible to have humans play some role in that. You can envision many scenarios. You can envision scenarios in which samples are launched into orbit around Mars, and then are retrieved by a human mission that goes into Martian orbit and comes back to Earth. There are many, many ways to play this game. But it is quite possible to do a return sample from Mars completely robotically.

Senator HUTCHISON. And is that a worthy goal that we should be looking at for one of the—I think all of you and we have talked about the stages. I think your message is a clear mission in stages so that you accomplish a mission, and that leads to the next mission, and we know what that is.

So would we be looking at something that would go to Mars while maybe the *Curiosity* might still be working, but yet another one that might have the return capability that would be a next goal to achieve, again looking toward humans going to Mars as a goal down the road?

Dr. SQUYRES. The Mars sample return campaign that was recommended in the planetary decadal survey would have kicked off with a launch in 2018. And it is still possible to do that.

Different opportunities to launch a spacecraft to Mars are different from one another. Some are energetically more favorable than others. It turns out that 2018 is one of the best opportunities in the next few decades to actually land a substantial payload on the surface of Mars.

And so it would be possible, given adequate funding, to do a mission in 2018 when *Curiosity* we hope will still be going. To put a rover on the surface that would select a carefully chosen cache suite of scientifically chosen samples, which would then be brought back to Earth by subsequent robotic missions further downstream. And that indeed was the primary recommendation of the most recent NRC decadal survey.

Senator HUTCHISON. Looking at it from the congressional standpoint where we also have to look at our financial situation and put money that is available toward the best priority, is that the best priority use of our exploration funds to do that, or would it be better to not put the money on that returnable vehicle, but keep going toward the human vehicle as the next goal?

Dr. SQUYRES. I would sincerely hope that it is not an either/or proposition. Certainly as you compare Mars sample return to other missions that could be conducted in the field of planetary science by NASA's Science Mission Directorate, the single highest priority, as I said, that was identified via a broad 2-year consensus building effort in the planetary science community was to begin this campaign of returning samples from Mars.

Now that was not an attempt to compare the value of Mars sample return to the value of future human exploration—SLS, Orion, or anything else. That was not the study that was conducted.

My sincere hope is that as has been the case over so much of NASA's history, robotic space exploration and human exploration can go forward in tandem with one informing the other, motivating the other, providing a basis that drives us to send humans to these places.

So I sincerely hope that we can go forward with this sample return mission without it adversely affecting what I think is the critical development of SLS, Orion, and the other vehicles that we need to move humans out in deep space, including Mars.

Senator HUTCHISON. Do we know from what we have up there, whether it's something orbiting Mars or the rover, that the atmosphere will not be dangerous for a human—obviously in a space suit? But do we know for sure, from what we have evidence of, that it will be safe for a person to actually land there and stay for a while?

Dr. SQUYRES. We are in the process of obtaining that information right now. *Curiosity* has a number of instruments that will bear directly on that question.

There is an instrument that is a radiation detector that is specifically there to characterize the radiation environment at the Martian surface as it would affect future human explorers. There is a capability to measure the composition of the Martian atmosphere to exquisite precision. We have an instrument that will tell us what minerals are present in the Martian soil, and you can infer from that what would be the effect of breathing that stuff, that kind of thing.

So we are right now—this is a great example of how these robotic missions inform the process of sending humans, just as back in the early days prior to Apollo, there were missions that were sent to orbit the Moon to land on the Moon, the Surveyor missions to characterize the compaction state of the soil. What happens when footpads touch down on it? Was the lunar module going to sink out of sight? We answered those questions with robotic precursors. We are doing the exact same thing on Mars right now.

Senator HUTCHISON. OK. I want to ask you, you said that we should prioritize the dollars that we have toward the best achievable goals in space exploration. And I think—I believe all of you

have stated that you are for robotics, and you are for human, and you do not think they are mutually exclusive.

Here is my question. Is NASA's mission too broad to be able to fully fund the priorities, and should we in the next NASA authorization look at splitting NASA, so that—we are now National Aeronautics and Space Administration. Should we, as an example, look at space exploration and put aeronautics somewhere else? That is just one example, or are there other examples? So that is a twofer.

Should we look at splitting NASA, or is the aeronautics and space function so closely intertwined that they are stronger and more appropriate together, even though we are spreading dollars now pretty thinly along with the science mission that is so important, like the Webb and the Hubble.

So I'd like your suggestions as scientists on that issue.

Dr. KENNEL. With regard to—there are other ways to slice up the piece. But with regard to aeronautics, it is performing several functions for the government, and the FAA in particular, that nobody else is. And actually, the amount of money that you would get for it and that you could devote to exploration would be so small, that I do not think it is worth the turmoil and disruption that would occur in a program that is already pretty small.

As far as the rest of NASA is concerned, I believe that the way the science program is funded at about the $5 billion level, gives us a shot at leadership in each of the fields that we are pursuing. And I think that is the criterion, and that we have several that—well, it gives us a shot at leadership, and each one that we are pursuing.

There is one area I think that is underfunded, which would be the utilization of the space station. And that actually is going to be critical in two ways. First of all, it will prove to people that we are still doing things in space, and second, there are a number of critical basic science things that need to be learned to do the space technology of exploration. And just simply learning how fluids, and pumps, and various other things like that, behave in space where there is no gravity, will inform the design of systems that will go beyond low-Earth orbit. That is just one example.

So I think that the science program would suffer tremendously if it were cutoff from the human and made separate from the human space sight enterprise.

Senator HUTCHISON. Any differing views, or is everyone——

Dr. KENNEL. These are my views based on my experience.

Senator HUTCHISON. And are you basically saying, and I would like any other view, that we are better off with NASA as a unit as it is, and there is not any part of NASA that you would jettison in order to get more of the money for the focus issues that we all agree are so very important.

Dr. KENNEL. I think you could look at each of the programs and ask what should we not do in order to do something new in the future. But at this level of just, you know, the basic elements of NASA, I do not see any value in separating them at the present time.

Mr. MASER. Yes, that was going to be my comment is, as Dr. Squyres said, with the limited budget we have, we are asking NASA to be all things to all people. And so the first step in my

mind would be, what are true priorities? And at some point—I mean, in business we do this all the time. I get requests for my research and development effort. Generally every year the requests come in at twice my budget. And so we go through and decide, you know, these are the priorities for us, and these—you know, we call it the water line. Anything below that does not get funded. If something above it goes away or does not work out, then it can buy its way back in. But we make those hard choices.

So the first step would be is, have we really made those hard choices and set a water line? And what then falls below it from a priority standpoint?

But then the question comes, your question was, should we split it off somewhere else and have them not do it? If we still think it is important and someone else is doing it, we are still not saving any money. So if the objective is to work with a limited budget, I am not sure just splitting it off and asking someone else to do it will save that.

And so, Dr. Squyres, you suggested we have some choices, and I agree. One of them I think maybe we have to fix some priorities. One of the other choices was maybe some of this effort could be shared with international collaboration, and so it reduces the total burden on one agency in one nation to fund it themselves. And we would have to decide which areas are relevant for that.

And then the third—you gave four choices, but those are the two that jumped out at me. But a third one we have not talked much about, but we in industry have worked on, is giving more results for less dollars. And so we have focused as an organization on how do we become as efficient as possible, and for every dollar—taxpayer dollar we spend through our customers and not just NASA—we work for the Air Force also—how can we provide more for that limited number of dollars? Are we organized properly? Do we have the right footprint or square footage for what we need and who we need to be in the future going forward? And I think that is a legitimate question to ask.

Senator HUTCHISON. Well, before we go to Dr. Squyres, the reason I opened the question of should we take some part of NASA that is considered maybe not synergistic with the purposes that we believe science, aeronautics, and space, could it go to another place where it could be done more efficiently because it matches better?

So the Department of Energy maybe for some of the energy science that we are using the Space Station for or something in the Department of Defense for aeronautics?

Dr. SQUYRES. Right.

Senator HUTCHISON. I don't know, but that is one way of at least looking at it. But if you are getting down to the priorities then, make suggestions on what you would put in the lower category from the scientific standpoint without the political overview. Are there programs within NASA that would get enough money over to space exploration or science to make it worth looking at lowering the priority?

I know you, Dr. Squyres, mentioned that you have to prioritize, and you have. So is there a scientific view of what should be lower priority where you could add to the space exploration side?

Dr. SQUYRES. Sure. I would like to actually make two remarks in response to your question. First of all, let me just say a quick word about aeronautics.

In my time as Chairman of the NASA Advisory Council, I have personally come to the opinion that the aeronautics program is really one of NASA's shining jewels. It is a small part of the agency. It is the first "A" in NASA. It is a small part of the agency financially.

But if you look at NASA's budget and you ask yourself what are the things that the agency does that most directly benefit the taxpayers in their daily lives, it is hard to find anything better at NASA than their aeronautics program. And I fear that disrupting that program, taking, trying to rip it out of the place where it has found such a good home and place it somewhere else could be detrimental to what I think is one of the best things that NASA does.

With respect to science prioritization, the decadal surveys that are run by the National Research Council are pure exercises in scientific prioritization. And when we conduct a decadal survey, we look at, oh, gosh, dozens of mission concepts. And we winnow them, and we winnow them, and we prioritize and prioritize. And we draw on inputs from the scientific community that go on literally for a couple of years.

And then what we bring forward are the few highest-priority missions that have survived that really pretty brutal down-select process. So the missions that you see in the decadals are the highest priority, the ones that result from a very, very intensive and very rigorous prioritization process.

Senator HUTCHISON. Yes, Dr. Kennel?

Dr. KENNEL. Yes, if I can add to that? One of the new things that we did in this round of decadal surveys was to try to impart some budget and engineering realism to our recommendations. And so, in addition to scientists, we included engineers, and we got independent cost estimates so that we looked at the practical realities as well as the ideal scientific goals.

And our recommendations were a result of those two types of considerations. And in the event, what happened was we recommended many fewer missions than we had in the past. And in fact, in our astrophysics survey for the entire decade, there were a number of smaller missions in the explorer program, but only one lead candidate.

And so, there was winnowing that took place that we thought was fairly rigorous. The budget is going to winnow us even further. But when you look at those leadership recommendations and look through them, then it is still important, I believe, to try to stick to the goals that they laid forth because those were analyzed for both scientific leadership purposes and realism.

Senator HUTCHISON. Let me ask you this. You mentioned better utilizing the Space Station as one of the things that we ought to do because there may be a term limit on that of 2020. And one of the things that we put in our authorization bill was to make the U.S. part of the Space Station a national laboratory so that outside interests—other agencies, corporations, universities—could actually put experiments there and use it.

My question is, what other ways would you have to further utilize and better utilize the Space Station that we certainly invested heavily in producing, and it has now been extended, which is great. But it is extended even though we can't get to it on our own—with our own juice yet. But we will in the next few years.

And what would you suggest that we ought to be doing to better utilize it?

Dr. KENNEL. Well, first of all, let me just state that when the Augustine Commission basically recommended that we extend the lifetime of the station to 2020, we also suggest an indefinite extension in the sense that if people are finding it useful in 2018, they will decide to continue.

And it is that indefinite time horizon that is the important one that would enable people from the non-NASA community and from the outside world to have enough knowledge that the resource will be there that they can then begin to plan long-term utilization programs. And so, I think being open about the date that we close the station is terribly important.

Second, if you really look at it, the Europeans are doing a much better job of utilizing the station that we built than we are at the scientific level. And the reason is they weren't burdened with the financial difficulties of building it, and so they planned for the long term.

And they have developed stable scientific communities that look at the—that all of the things that you can do in low gravity that you cannot do on the Earth, whether it is fluid behavior, biological behavior in particular, and they have basic science research as well as engineering going forward.

Financial exigencies and program changes eviscerated our community in that field, and that happened about 2005 or 2006. Our report recommends that we rebuild that community, and we are very pleased that NASA has made a good faith effort to do so.

They have created an office. And with their limited resources, they are trying to rebuild a community that has lost faith, to be quite frank, that the station will be there for them.

That is why the NGO is needed to make it easy for them to participate. The long horizon is important for them so they can be secure that they can commit their reputations on station. And quite frankly, the funding that that office has is far less than the funding we used to have.

And so, I think a requirement for the U.S. is for U.S. scientists to begin to use it. And I think by 2020, if you begin to see U.S. scientific results coming out at the same international level that we are used to in all of the other fields of science, then I think people will no longer say that the space program is dead because we don't have the Shuttle. They will say, oh, America is doing lots on its Space Station.

But right now, the Europeans are getting more science out of the Space Station that we built than they did—than we are.

Senator HUTCHISON. Dr. Squyres?

Dr. SQUYRES. I have a specific suggestion regarding Space Station utilization. If you are, say, a university researcher who is interested in doing research in a microgravity environment, there are

substantial barriers to trying to get an experiment onboard the Space Station.

There is a level of review and oversight, what some researchers might view as excessive attention to minute details of experiments that are daunting to many university investigators. It is just too hard to get through that process and get your hardware onboard the Space Station.

So, anecdotally, there are researchers who just choose not to try it because they don't want to jump over those hurdles. Now the reasons for the existence of those hurdles are absolutely sound, and they are crew safety. And crew safety can and must never, ever be compromised.

But now that we have years of experience in operating the Space Station, I think it might make some sense to look carefully at whether or not there is a gap that could be widened between what is really necessary to safely fly something on the station and what the current set of rules, requirements, reviews, and oversight demand.

And if that gap could be widened a little bit, reducing the barrier to getting universities, getting other organizations to fly experiments on the Space Station, just making it easier to do business in that precious national laboratory, I think there could be some benefits to the Nation.

Senator HUTCHISON. Thank you. That is very helpful.

Dr. KENNEL. And if I could add, this barrier that he so cogently described is the one that we thought the independent NGO organization could overcome. That what you really need is a professional organization that can take the requirements and hopes of a space-naive community and translate them into terms that the operational community can tolerate and work through all of the issues and not make the poor scientist out there who has never before worked in space try to deal with it.

So you need a professional opportunity translation organization, and that is why we thought—and there is an example in the Space Telescope Science Institute that has guided my thinking. But something like that is needed to actually translate opportunity into reality on station operations.

But at the end of the day, the provision of access to the zero, low-gravity will be an attraction to many scientists if they can actually get at it.

Senator HUTCHISON. OK. Let me ask you, I have a couple of other questions. One is on the—you said we should have more not just participation, but real use with our international partners in both, obviously, the Space Station, but in space exploration. Do you have any specifics on what more we should be asking and realistically expect from our international partners?

Dr. SQUYRES. Sure. Let me give you two examples.

In the area of robotic space exploration and particularly sample return from Mars, there are several necessary elements to a sample return campaign. One is a rover that can land on the surface and collect and cache a suite of samples. Well, that is something we know how to do pretty well at NASA. So maybe we don't need any help with that one.

But you also need a vehicle that can get those samples off the surface and into orbit around Mars. And then you need a vehicle that can find that little spacecraft that you have launched off the surface, that can rendezvous with it and bring the samples back to Earth.

On-orbit rendezvous, planetary orbiters, these are things that many potential international partners know how to do and know how to do well. And so, I think there is significant potential. Indeed, that was the intention of the planetary decadal survey recommended sample return campaign was that it would be conducted in partnership with other agencies, particularly the European Space Agency.

Senator HUTCHISON. But why aren't we doing that?

Dr. SQUYRES. The reason we are not doing that at the present time is the cuts that were projected to the Fiscal Year 2013 planetary budget made it impossible, projecting the budget forward, to carry out that hoped-for mission in partnership with ESA. And so, NASA walked away from the partnership, at least temporarily. My hope is that that can be corrected in the future.

With respect to human exploration, I made the point in my opening remarks that we have two magnificent pieces of what you need for truly enabling deep space exploration, the Orion and SLS. But Orion and SLS alone will not get you to the surface of the Moon. They will not get you to an asteroid.

There are other vehicles—a lunar lander, a deep space habitation module that can support a crew for the time that it takes to actually get to an asteroid, in-space propulsion capabilities. That sort of thing. I think those are all potentially components of a true deep space exploration system to which international partners could potentially be invited to contribute.

And so, in my opening remarks, I stressed that there is a big piece of the puzzle missing. We say we want to go to an asteroid. We say we would like to maybe go back to the Moon. We certainly want to go to Mars. But right now, what we have is the ability to launch a lot of mass off the surface of the Earth with SLS, and the ability to support a crew of 4 for 21 days with Orion.

Those are magnificent and necessary capabilities. They are necessary, but they are not sufficient. And so, I think looking to capable, committed, international partners, as we have done so spectacularly well with the International Space Station—I mean, what a triumph that has been—is something we should be looking at.

Senator HUTCHISON. Yes, Dr. Kennel?

Dr. KENNEL. I would just like to add to that. The International Space Station partnership is a miracle of international relationships. It has survived budget ups and downs, our accidents, various defaults on the part of other partners, and yet it continues to this day as 14 nations working together on the station.

And if you think, for example, that someday that the world will go to Mars led by the United States, then you are going to need something like the Space Station partnership, and the confidence building that has already taken place, to also participate in that mission.

And so, there is a policy issue that you may wish to consider. That is that, as people renegotiate the International Space Station

partnership, you could add to it some goals that are related to the development of the technology for beyond LEO exploration to the Space Station partnership so that they begin to develop an awareness of the really great challenges and technical challenges that will face all of us as we try to get to Mars, and we begin to enlist them in the effort.

And that could—I don't know whether that would serve as a precursor for the partnership that we would build, but it certainly would be a confidence builder. And I think it would help start the process off in a way that is useful to the United States.

Mr. MASER. One other comment I would add to that is we are all aware that the Space Station was nearly canceled, right, within one vote. And a lot of people have said one of the main reasons it went through is because of our international commitments.

And I would argue, a big part of my argument has been about an enduring, stable vision of incrementally increasing challenges. And if we committed to that and committed to a collaboration internationally for that over the long run, perhaps that is a model in which national commitments to each other create some stability and can get us out of this cycle of starting and canceling things because it goes beyond any one administration or any one congressional period because the commitments are multi-decade.

Senator HUTCHISON. I think what you all are doing is actually putting forth the long-term, clear goal that you discussed as the first policy directive. Because it would take certainly to get our international partners to re-up into this bigger coordination effort the assurance that we wouldn't have fits and starts.

And one of the things in my time here that I have worked with administrations that are Democrat and administrations that are Republican and have tried to say you can't just say we are going to stop doing something that we have international partners already investing in to a great degree from their own budgets. Their percentage of the budget they are putting in is as big as the percentage of our budget.

And we have got to be a reliable partner in order to keep an alliance like that going. And if we are talking about the kind of commitment that you suggest, which is putting different vehicles' capabilities together so that it doesn't all fall on us, nevertheless, we are going to have to be reliable and show that we are not going to get cold feet mid-way through this and all of a sudden stop our part.

And I think that is a worthy goal for the clearly-stated visionary goal for the future, and I think you have sort of put together a nugget that really could be the basis for the next authorization bill.

Last question, and then I will turn it back over to the chairman. And that is we have seen really an emergence of commercial capabilities. A lot of our U.S. tax dollars have gone into helping the commercial operators begin to get the capabilities to at first do this taxi to and from the Space Station.

Are you at all concerned about the money that goes into the commercial operation taking from the future heavy launch with the discussion that we have just had? Or do you think that we can do both efficiently, having the taxi to the Space Station and perhaps allowing it to be extended, as Dr. Kennel suggested?

Because you have the taxi capabilities going forward beyond 2020, and maybe it could maybe not pay for itself exactly, but certainly offset much of the expense of holding on to the Space Station. While we, at the same time, focus our efforts at NASA on the next generation, the beyond low-Earth orbit exploration.

Dr. SQUYRES. I think if we are smart about it, we can do both, and let me give an example. We were just talking about the importance potentially of international partners bringing pieces to the puzzle to create a more robust deep space capability. But the resources to do that within ESA or wherever, they have to come from somewhere.

If you look at ESA's, for example, or some of our other international partners' commitments to future Space Station activities, some of them have to do with resupply. Some of them have to do with providing "up mass," getting stuff up to the Space Station.

If, as a result of investment in commercial capabilities—the recent Dragon mission to station being an example, and more to come, I hope—if we develop a robust capability here in this country to do that resupply, to get that up mass to the Space Station, it could offload some of these foreign partners from some of the resupply that they are currently committed to providing. And they could take those resources, and they could put them into something else that would take us deeper out into space.

So I think if we are smart about how we play this game, there are efficiencies that could come from commercial taxis, if you will, to the International Space Station that could provide benefits that could then be felt in the deep space part of what NASA does.

Senator HUTCHISON. Thank you.

Dr. Kennel?

Dr. KENNEL. Thank you.

There is no long-term future unless you provide value in the short term. And so, the trips to the station are providing value in the short term. And the commercial enterprise, if it proves to be successful I think is going to broaden the social base of and technology base for the larger enterprise to come. So I think that is a useful thing.

There is another dimension of this problem that you may not become aware of. But recently, with the cancellation of the Delta rocket system, the space science community has become concerned about the lack of availability of mid-scale rocket systems for scientific spacecraft.

So there is a kind of unfocused hope that if the commercials are successful, then we will also be able to tailor some of our experiments to those capabilities. I haven't quite seen the study yet, and I think it is delicate at the commercial level to do it. But I do believe that there is a possibility that a successful commercial industry will also help space science.

Mr. MASER. I guess my comment is, first and foremost, I think we all agree we need access to station from the United States. And so, given that, both cargo and crew. And given that, we want to do it as affordably as possible.

And Neil deGrasse Tyson said low-Earth orbit is where hundreds have gone before. And I think the point behind that is we have been doing that long enough. We should be able to do it very cost

effectively and potentially buy those services in a different manner than we have traditionally procured them as a NASA owned and operated vehicle. So I am onboard with that completely.

And certainly, cargo as a separate launch vehicle and a separate system we can take more risks. We can afford a little bit of failure in there, and I think that is good.

The real question in my mind is, as you shift to commercial, we are not going to be as risk tolerant. You have the lives of people onboard, and you have the Space Station that you absolutely have to be careful with from that standpoint also.

And so, when I stand back and look at it, my question and comment would be are we absolutely certain that the approach we are taking is the quickest, most cost effective, and safest way to take things to station, especially people? And how many systems do we really need under that context with the amount of market there is out there?

Because when I look at particularly commercial crew, when I stand back and look at it, if station were to end in 2020, the commercial crew people would end up, if there is two providers, would end up launching each once a year for maybe 3 years or 4 years or something. So maybe station will be extended, but the real question is for the most effective use of dollars, how many commercial crew providers do we need in the long run is my question.

Senator HUTCHISON. Well, we have certainly tried to lower the number of commercial operators that are going to get the Federal seed money just because I think we agreed that that was just more than we could take away from SLS and Orion.

But now they are at two and a half. So——

Mr. MASER. And a half. That was positive movement. I think that is good to get to the next point, and I think as it evolves to the next decision point, I think clearly we need to look at how many real missions are there out there, and how many suppliers are appropriate?

Senator HUTCHISON. Well, the goal is to have one. So that is the goal, and we are looking at the efficiency and making sure we are not paying just as much as we would had we kept it all in NASA. And I think the down-select, which we pretty much forced, is a step in the right direction.

But hopefully, there is one more down-select, and based on the merit, whoever wins will be the one, hopefully.

Well, thank you very much. This has been very, very helpful, and I think that it really will inform us as we go forward into the next authorization period.

And fortunately, even though I am leaving, there will be others who will be staying and the staff will, hopefully, stay, and we will use this very helpful information to look at the importance of a goal that can be achieved with international cooperation. I like what you have said.

Thank you very much.

Mr. MASER. Thank you.

Senator NELSON. Thank you, Senator Hutchison. And thank you again for your leadership over the years on this topic that you are very, very passionate about.

I just want to say, Mr. Maser, that the value of competition is that instead of your rocket company being the only one in town, you get sharper, your prices get sharper if there is a competitor there. And that is the whole idea of this competition for the way to get to and from the International Space Station. So over time that the bringing of the cost per pound to get to orbit comes dramatically down.

I want to ask you all on our topic of exploration beyond Earth orbit, doesn't it appear right now that with conventional technology that we couldn't do—assuming that we can build a lander and all of that and that we know what we are landing on and we have returned a sample so we can know what to expect. But right now, it is going to take us 8 to 10 months to get there.

Once you are there, then the planets are out of alignment that you have got to wait a long, long time before you can bring the crew back to get the planets closer in alignment. So aren't we really talking about going to Mars in the 2030s for the first crewed mission that we have got to develop a whole new propulsion system that is going to get us there a lot quicker?

What do you think about that?

Dr. SQUYRES. Personally, I think that it is possible to do a human mission to Mars using advanced, but chemical propulsion systems. I don't think we need a dramatically new technology. There are technologies that will be beneficial. One can imagine aero-capture deceleration technologies that could be used at Mars, for example.

Certainly for some of the transfer stages that we might want to use to get crews to Mars, having the ability to do in-space storage of cryogenic propellants would be a good thing. But I think if you were to conduct a poll in the astronaut office right now of who would be willing to sign up for a mission of that duration to Mars, you would get a lot of takers.

So I personally believe that the biomedical issues that are associated with long-term exposure to microgravity and the effects on a crew on the way to Mars and back are being addressed now pretty impressively on the International Space Station. I think that is one way in which ISS is really contributing to future human exploration.

So I don't think you need a totally different approach to in-space propulsion in order to safely get humans onto the surface of Mars, have them be effective while they are there, and get them back. But there are technological developments, and I think in-space storage of cryogenic propellants is very high on that list that will be enabling in that regard.

Senator NELSON. Dr. Kennel?

Dr. KENNEL. I am not going to challenge Steve's judgment because I actually agree with it as things look at the present. However, what I would like to say is that the commitment to the goal probably is going to stimulate all sorts of technological innovations. People are going to try things to try to shorten the flight time.

They are going to try various biomedical remedies and so forth because they know the goal will still be there. And soon as you make it clear that we are going to eventually go beyond low-Earth orbit, I think you will find people willing—just like the entrepre-

neurial space launch industry, you will probably find people willing to take a risk on new technologies, and experience tells us that every now and then there is a breakthrough.

And, that that may accelerate. The goal will be for those technologies to accelerate the time that we shove off from low-Earth orbit and actually make the first mission. And so, I think setting the goal is terribly important for eliciting potential innovations.

Senator NELSON. I want to wrap up the hearing with just a couple of questions about the funding and the certainty of the funding. Now we are living in uncertain times with the budgetary situation as it is. If you look at NASA as a Federal agency, compared to other Federal agencies, it has fared quite well. And yet what is the future?

Sequestration, this meat cleaver that is hanging over the Federal budget at the end of the year, was never intended to take effect because it was the meat cleaver to force the House and Senate joint super committee to come to agreement, and we know what happened a year ago. That didn't happen, and so we are facing those consequences.

But I think we will work ourselves through that and avoid the sequestration. But still the uncertainty of the funding of the future.

And Mr. Maser, we are getting ready, probably tomorrow, to enact another appropriations bill called a continuing resolution, taking the existing funding from this past fiscal year and applying it probably for the next 6 months. That creates uncertainty for NASA programs and contractors. How in the past have the continuing resolutions affected NASA programs and contractors?

Mr. MASER. Well, this year it might be a good thing, I don't know, relative to what we have been looking at potentially. But generally, what we look for is a view to what funding is going in out-years, and we size and organize around those.

And then as a budget isn't approved, you go into a continuing resolution, activities and scope and funding for things you had planned on, staffed for, and organized for don't materialize, and you are forced to move people around and shift priorities. And in some cases, you can't adjust your costs fast enough that you just have to pass on the cost increase to the customer in the short run.

In the past few years, there has been probably I think it has even been more discontinuous than the transition from the end of the Apollo program to the Shuttle program because there was actually quite a few years of overlap in development activity. So even though Apollo was ending, Shuttle had started years before its first launch, and it continued to keep going.

And so, that actually provided—even though it was much reduced in terms of what it was during the Apollo era, you pretty much knew where it was, and it wasn't discontinuous. In the past 3 or 4 years here, we have seen the end of the Shuttle, cancellation of Constellation, no decision at all about what we were going to do next.

Finally, a year ago, a decision was made. But every year——

Senator NELSON. Two years ago.

Mr. MASER. It was 2 years ago? I thought—well, the authorization was 2 years ago, but the SLS was a year ago, the actual decision on the SLS, I believe.

Senator NELSON. No, sir. The authorization in 2010 set the course, the blueprint, for the SLS and set the parameters.

Mr. MASER. That is true.

Senator NELSON. Now you are talking about the funding of it. Well, the funding—and there again, I thank Senator Hutchison because she is on the Appropriations Committee as well. The funding started to implement the authorization bill for the development of the SLS and Orion.

And of course, in appropriations process, you always have these pulls and tugs. And then, with the overall attempts at slashing Federal spending on everything, that has complicated it.

Go ahead and make your point.

Mr. MASER. That is true. So——

Senator NELSON. I just wanted to correct that.

Ms. MASER. Thank you.

So the ultimate comment I would make is every year in 2010, 2011, and 2012, we have made reductions down to the size we felt would be appropriate for our business going forward, starting in 2010.

As we get toward the end of the year and we look towards what is going forward in the future in terms of budgets, how many is being allocated funding, et cetera, we had to make additional reductions, and this is my third year of reductions. And every year I say once I get down to that level, I will have a stable employment level about which I can manage fluctuations with overtime and basically temporary workers.

And so, that is the intent we are doing this year. We are continuing to reduce staff. We are down about 30 percent in staff over the past 3 years. And the continuing resolution, sequestration, and the lack of stability creates a tremendous amount of nervousness within the organization, within our people about what the future holds for them, and it creates a big challenge for attraction, retention, and motivation going forward.

So we can organize and size for any future. But we would like to see a view as to what that future looks like and some stability for the long run.

Competition is fine. We are happy to compete, and if we lose, we will make adjustments. We would love to go compete for those items that we put out there in the future. But to have them not funded and never even be able to compete for them or to compete and win and then have them canceled is a real challenge for our organizations.

Senator NELSON. Dr. Kennel, I would suggest that in your position with the NRC's Space Studies Board, you might want to have them look at this topic—the impacts to the space program of the different funding scenarios, including sequestration, even though this Senator doesn't think sequestration will go into effect. Or if it did go into effect because of lack of agreement by December 31st, it will quickly be overturned in the new Congress.

So I would suggest that you all take up that topic fairly soon.

Dr. KENNEL. We have given this some thought, and it is quite clear that giving the decisionmakers a sense of what is at risk at different levels of reduction will, I think, be very useful. It will be difficult, I think, for us to do it over the next 3 months. But I think

over the longer term, we can look at levels of cuts or changes in budget and how we might respond, and we would do so with reference to the goals thus far that we have set forth in our decadal surveys unless we are directed to look at it differently.

But I think we could—knowing our goals, we could say what we would do under different scenarios.

Senator NELSON. Dr. Kennel, it would also be helpful if you could report from the NRC to us on the Committee on an evaluation of the administration's plan under the NASA authorization bill for the exploration program with regard to Mars. That would be very helpful.

Dr. KENNEL. Yes, I would be delighted to consider that. We would have to work it out very carefully, of course. But we very much want to see what the new NASA committee is saying. We very much want to evaluate it.

Senator NELSON. Good.

Senator Hutchison, any further?

Senator HUTCHISON. No, thank you.

Senator NELSON. Well, this has been most illuminating. Thank you all.

The meeting is adjourned.

[Whereupon, at 4:10 p.m., the hearing was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF HON. JOHN D. (JAY) ROCKEFELLER IV, U.S. SENATOR FROM WEST VIRGINIA

Fifty years ago today, President Kennedy gave a now famous speech at Rice University highlighting his challenge for our nation to go to the Moon and back. Within that turbulent decade, Neil Armstrong set foot on the Moon's surface, in the Sea of Tranquility. We honor the legacy of President Kennedy, Armstrong, and all those who worked to achieve the triumph of the Moon landing as we continue to pursue the frontiers of science and technology. President Kennedy's challenge was motivated by the need for the United States to be the world leader in science and technology. Although the global environment has changed much since the Cold War, the need for our country to remain a leader in science and technology has never been greater.

There are many ways to explore—whether it is by probing the depths of the oceans, peering into the eternity of the cosmos, or unraveling the marvels of the human body—exploration pushes the boundaries of human understanding and knowledge.

Today we are here to talk about the exploration of space. As President Kennedy said of space, "Its hazards are hostile to us all. Its conquest deserves the best of all mankind." Whether we explore with humans or robots, we face challenges that push us to the limits of our science, engineering, and ingenuity.

We saw that ingenuity proven when we landed a rover the size of a small car on the surface of Mars just over a month ago. The *Curiosity* rover touched down on the Red Planet after a so-called "seven minutes of terror" culminating in a graceful lowering to the surface by a "sky crane." This spectacle was watched by at least 4.7 million people around the world, inspiring numbers of students in their science and math studies so that they will go on to lead our next incredible journeys of exploration.

There are many ways to explore space—and we have a variety of destinations between the Earth and Mars to consider. What is most important is that we continue exploring, continue probing the frontiers of science and technology, and continue inspiring and educating our next generation.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO STEVEN W. SQUYRES

Question 1. What flight rate for SLS would be required for a human mission to Mars and, beyond funding to buy the additional hardware, are there any major obstacles to NASA from being able to achieve such a flight rate?

Answer. The flight rate currently envisioned for SLS is substantially lower than for any previous human-rated launch system developed or used by NASA. I do not consider this low flight rate to be a technical show-stopper for an eventual human mission to Mars. Rather, my concern is that such a low flight rate could make it difficult to maintain flight team proficiency and, especially, program momentum. So what constitutes an appropriate flight rate for SLS is more a matter of opinion than objective engineering fact. Personally, I would like to see the SLS flight rate doubled. Other than funding, I see no major obstacles to achieving this.

Question 2. What types of science and technology objectives could be accomplished with a human mission to the Mars system that stops short of an actual landing on the surface?

Answer. There are several, including (but not limited to) the following:

- Validation of the propulsion, life support, and other technologies required for safe transport of crews to and from cis-martian space.
- High-bandwidth real time tele-operation of robotic vehicles on the martian surface, allowing substantially improved science return.

- Collection and return to Earth of sample caches that have been gathered on the martian surface and placed into orbit by robotic vehicles.
- Exploration of the martian moons Phobos and Deimos, which are probably captured asteroids. The surface soils of both moons should also be rich in materials that were ejected from the martian surface by impacts.

Question 3. NASA's funding for FY 2012 was well below what was authorized by this committee, as is the amount requested by the President for FY 2013 and the amounts reflected in the FY 2013 appropriations bills that have yet to be enacted.

Please evaluate the sustainability of NASA's exploration program given the current budget trajectory.

Answer. I fear that NASA's long-term program for human exploration of space may not be sustainable under the current budget projections. These budget projections yield an unprecedentedly low flight rate for SLS and Orion relative to past human-rated systems, no capability for exploration of the lunar surface or beyond cis-lunar space, and little margin for unexpected difficulties.

Question 4. Given the current budget trajectory for NASA, what specific types of contributions would international partners need to make for us to achieve a sustainable deep space exploration program?

Answer. In my opinion, international partners could contribute most to a sustainable program of deep space exploration by providing necessary vehicles that NASA currently has no funding to develop. One such vehicle could be a deep-space habitation module capable of supporting a crew for the extended period of time necessary to travel to an asteroid, explore it, and return to Earth. Another could be a lunar lander.

Question 5. If we continue to see a reliance on stop-gap, short-term spending measures moving forward, what strategies can be employed in lessening the impact of such measures on NASA's exploration program?

Answer. Year-to-year volatility in NASA's funding is one of the most serious challenges the agency faces. I cannot envision a strategy that will completely mitigate this problem if it persists. I would suggest, though, that forging strong international partnerships could help. If NASA's international partners have a significant and unwavering commitment to a joint program of exploration, that commitment could provide a stabilizing influence. Of course, maintaining a partner's commitment in the face of NASA's year-to-year uncertainties is itself a challenge.

Question 6. We know that NASA's plate is full with a balanced mission portfolio and priorities in developing the SLS and Orion, supporting and fully utilizing the ISS, and launching a successful James Webb Space Telescope, not to mention continuing the agency's aeronautics research, Earth science, technology development, education, and space science efforts.

Given our exploration and science priorities, if NASA's budget remains on its current flat trajectory, what capabilities should the agency reconsider to free up its resources?

Answer. In my opinion, NASA's commitments to aeronautics, space and Earth science, technology development, and education should continue strongly and indefinitely. The current plan for the International Space Station calls for it to be decommissioned in 2020. The eight years of on-orbit research that will take place between now and then should reap much of the potential remaining benefits of ISS. Just as was the case when the Space Shuttles were taken out of service, the decommissioning of ISS on the planned schedule should free up resources that can be devoted to other human spaceflight activities.

Question 7. One of NASA's design reference missions for a crewed visit to the Martian surface calls for plutonium-238 to power surface hardware, for example. Is plutonium-238 likely to be needed for a crewed mission to Mars? If so, is the Administration's plan to restart production of plutonium-238 sufficient to support such a mission in the 2030s?

Answer. Plutonium-238 could be useful for some aspects of a long-term Mars exploration architecture, especially one involving both humans and robots. However, I do not believe that it is a hard requirement, nor that availability of Pu-238 should be viewed as a limiting factor for future human exploration of Mars.

That is not to say, however, that production of Pu-238 is unimportant. In fact, it is crucial for many of NASA's future robotic deep space science missions.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO CHARLES F. KENNEL, PH.D.

Question 1. What types of science and technology objectives could be accomplished with a human mission to the Mars system that stops short of an actual landing on the surface?

Answer. There would be a substantial gain in our understanding of the human health and technical challenges of long-duration space missions if humans were to travel to the Martian system without actually landing on the surface. This was certainly true for the early Apollo missions to the Moon, but given the vast distances involved and large costs of any mission to the Martian system, a comprehensive analysis of the scientific, technological, and operational value, as well as public appeal, of a staged approach to going to Mars is needed.

Some have proposed that some preparation for an eventual human mission to Mars could be accomplished by means of remotely operated robotic assets placed on Mars' surface. In some scenarios, the humans operating the surface assets are in orbit around Mars, or on the surface of a Martian moon (for example, Phobos). These locations would have a short communication time to Mars' surface, and may make human decision making more effective. Some of the assets on the surface, such as rovers for geological exploration or cached samples of Martial material, could be devoted to science.

Since it is much cheaper to land on and return from Phobos rather than on Mars' surface, the Phobos option could be financially attractive. Returns of samples of material from Phobos would provide valuable information about the evolution of the Mars system. The Phobos option was discussed informally during the deliberations of the Augustine Commission, but has not had rigorous review.

The first priority of the recent SSB Decadal Survey of Planetary Science, "Visions and Voyages", is a mission that collects and caches samples of Martian soil for eventual return to Earth and comprehensive study in the laboratory. The return could be accomplished by relaying the samples to astronauts in orbit or on a satellite, or by robotic liftoff direct to Earth. The constraints placed on the science achieved by the different operational scenarios need to be assessed.

Finally, to my knowledge there has been no independent assessment of the relative value to science of a human presence "on the ground" and remotely-operated robotic exploration. Certainly such a study may provide useful guidance to assess this relative value while also considering the technical risk and affordability of various scenarios.

Question 2. NASA's funding for FY 2012 was well below what was authorized by this committee, as is the amount requested by the President for FY 2013 and the amounts reflected in the FY 2013 appropriations bills that have yet to be enacted. Please evaluate the sustainability of NASA's exploration program given the current budget trajectory.

Answer. The SSB has not formally assessed the sustainability of NASA robotic and human exploration in the current budget environment. The upcoming study by the NRC's Committee on Human Spaceflight, which was requested in the NASA Authorization Act of 2010, will consider the factors that contribute to the long-term stability of human exploration. In my recent testimony, I argued that a stable commitment to long-range goals is essential to program stability in unstable budget circumstances.

One of the principal outcomes of the Augustine Commission was to extend the life of the International Space Station (ISS) to at least 2020. In my personal view, this decision enables human spaceflight to be sustainable until a program of deep space exploration is up and running. Key to the future support of ISS will be effective utilization by the United States. In this regard, SSB's recent decadal survey, "Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era" recommends ways to reconstruct the U.S. science program, which was effectively shut down during ISS construction. NASA is making good-faith efforts to renew the program within available resources but its progress needs to be reviewed. In particular, there has been no provision to date for a mid-term review, by SSB or otherwise, nor is there a way to provide continuing independent scientific advice, as our standing committees do for NASA's Science Mission Directorate.

On the robotic side, SSB's recent decadal surveys include "decision rules" that were an outcome of a community consensus process. They were designed to sustain the stability of NASA space science programs should actual budgets differ from those provided to the decadals by NASA. Even though the current budget for NASA science differs substantially from what the decadal committees envisioned, the decision rules provide a reasonable menu of options for maintaining NASA science programs in a scientifically valid way.

The Space Studies Board is committed to providing long-range advice that is adaptable to short–term changes. We on the SSB are beginning to think about how to review mid-term progress in the implementation of each of our decadals. Sustainability is obviously a key issue and we will discuss to what extent our mid-term assessment committees should review the decadal decision rules in the light of recent events. The next mid-term review will be for Astrophysics in 2014/2015.

Our upcoming SSB workshop on "lessons learned" from the recent round of decadals will provide the first opportunity for the scientific community to discuss how to carry out the next round. One of the most salient issues will be how to recommend programs that are resilient to budgetary and technical change. At the present time, there is no plan for a more formal consideration and broader dissemination of the issues brought up in the workshop. I believe there could be benefit in a more deliberative exercise that translates the core messages from the workshop into new guidance for the NRC, the Congress, and the agencies.

Question 3. If we continue to see a reliance on stop-gap, short-term spending measures moving forward, what strategies can be employed in lessening the impact of such measures on NASA's exploration program?

Answer. Once again the NRC has not spoken on how the stop-gap measures you describe might affect the human spaceflight program but history tells us that not funding large-scale expensive technical endeavors at the required profile only leads to increased cost in the long run. Furthermore, measures like continuing resolutions make it difficult to start new initiatives or discontinue programs that are no longer are needed. It seems to me that if budgetary turbulence is prolonged beyond the near future a significant re-assessment of the agency's portfolio and implementation strategy may be required. The size and resiliency of its program must be made commensurate with the size and variability of its funding.

On the science side of exploration, I can only repeat that I remain convinced the consensus of the scientific community cannot be discarded in these difficult fiscal times. The decision rules the communities provided in their decadal surveys should guide us as we try collectively to lessen the negative impact budgetary turbulence is having on the conduct of science. Where those rules are no longer apposite, it seems to me the community should be asked, through the NRC, to consider new or modified rules that would enable the essence of its science priorities to be maintained.

Question 4. We know that NASA's plate is full with a balanced mission portfolio and priorities in developing the SLS and Orion, supporting and fully utilizing the ISS, and launching a successful James Webb Space Telescope, not to mention continuing the agency's aeronautics research, Earth science, technology development, education, and space science efforts. Given our exploration and science priorities, if NASA's budget remains on its current flat trajectory, what capabilities should the agency reconsider to free up its resources?

Answer. This is indeed a difficult question; its answers will be even more difficult. NASA pursues the Nation's interests in civil space and aeronautics on behalf of all of us, and it is a political decision on how to allocate funds to that pursuit. I do expect the upcoming NRC report on NASA's strategic direction may provide some guidance as to the types of decisions that would have to be made to maintain a clear and compelling strategic plan for the agency, although we should note that committee was not charged to recommend any one particular path.

Because of SSB's recently completed decadal surveys, and NRC's forthcoming studies on NASA's strategic directions and on the goals of the human space exploration program, the NRC is in an excellent position to support the Government as it grapples with NASA's future directions. Once again, I can only emphasize personally how important it is for the Congress, Administration, and NASA, to agree to support a clear and feasible set of long-term goals. With a consistently supported policy framework, both the human exploration and science communities will know better where to find new opportunities and where when necessary to make cuts.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. AMY KLOBUCHAR TO CHARLES F. KENNEL, PH.D.

Question. Mr. Kennel, in your testimony, you noted that we need to not only support inspiring leadership projects, like *Curiosity,* but also the smaller and equally innovative and scientifically useful and by doing this we will be investing in the capacity to innovate. American innovation is key to our economy and I think we need to continue to understand that investment is key to innovation. Could you talk about maybe a few of those innovations or missions NASA is involved in that may

not have the lime light but are necessary for the understanding of our world and surrounding universe?

Answer. Looking at NASA science overall, there is a remarkable concurrence of views among the disciplines in space science: a vibrant program of small and medium class missions is critical to finding innovative ways to explore the frontiers of each discipline.

Each NASA science division maintains a program of small missions designed to address important scientific goals on a timescale and at a cost significantly less than those of flagship missions (such as *Curiosity*). These missions go by various names, such as the Discovery missions flown by NASA's Planetary Science Division and the Small and Midsize Explorer missions sponsored by NASA's Astrophysics and Heliophysics divisions.

The planetary science decadal survey commented that:

> "Discovery missions can respond rapidly to new discoveries and changes in scientific priorities. Rapid (~3 year) mission development is feasible, providing opportunities for student participation, rapid infusion and demonstration of technology, and a rapid cadence of missions pursuing science goals. These missions are executable using relatively small launch vehicles."

Examples of such missions include the MESSENGER spacecraft, currently undertaking pioneering observations in orbit about the planet Mercury, and the planet-finding Kepler mission, which has revolutionized our understanding of planetary systems around other stars.

The astrophysics survey said of explorer missions:

> "Explorers have delivered a scientific return on investment at the highest level over the past two decades. The three astrophysics Medium-scale Explorer (MIDEX) missions launched to date—the Wilkinson Microwave Anisotropy Probe (WMAP), Swift, and the Wide-Field Infrared Survey Explorer (WISE)—have provided high-impact science for a combined cost significantly less than that of a single flagship mission."

In making an augmentation to the explorer program its number two priority in the "large scale" list of priorities the Committee wrote:

> "[the] high ranking is motivated by the Committee's view that expanding the Explorer program is a very effective way to maximize scientific progress for a given outlay."

The decadal survey in solar and space physics just published says:

> "the explorer program's strength lies in its ability to respond rapidly to new concepts and developments in science and to forge a synergistic relationship with ongoing, larger, strategic missions. The explorer program creates a highly competitive environment in which teams led by a principal investigator (PI) rapidly capitalize on advances in technology, enabling cutting-edge science at moderate cost."

Projects in this class of missions are cost capped and chosen via peer-reviewed open competition. Teams of scientists, engineers and technologists in academia, industry and government laboratories submit proposals. The open competition, together with the discipline imposed by the cost cap, encourages an entrepreneurial spirit. Winning proposals often pioneer the use of innovative approaches to maximize scientific return while minimizing technical and financial risk.

Response to Written Questions Submitted by Hon. Bill Nelson to Jim Maser

Question 1. What flight rate for SLS would be required for a human mission to Mars and, beyond funding to buy the additional hardware, are there any major obstacles to NASA from being able to achieve such a flight rate?

Answer. I don't know an absolute minimum number or rate of flights that would be required for SLS to support human missions to Mars. The number of flights will be dependent on what type of mission architecture is ultimately chosen and how it is implemented. I do know that a predictable and steady cadence of flights, supported with the proper funding and, most importantly, an enduring vision is key to the success of a Mars mission and SLS. As long as there is a long term vision that sustains the momentum, the industrial base will adjust and size to the program. In my opinion, the SLS program would benefit in terms of affordability, skill retention and a healthy industrial base if there were flights paced at no less than one per

year with additional launches based on the specific mission requirements. What absolutely cannot happen is the current trend of starts, stops, and redirection and budget uncertainty slowing the program. History has proven that under these conditions, critical know-how is lost, plant capacity and capabilities are shuttered and a gap is created between the generations of the workforce with little or no hope in transferring these very perishable skills. From our vantage point there are no major technical obstacles for NASA to be able to achieve a sustainable flight rate as long as the enduring vision and the funding for the mission are truly committed to and sustained in action, not just in words.

Question 2. How does the technological challenge of sending humans to the Martian system, but not landing on the surface of Mars, compare to the challenge of a human landing on the surface?

Answer. First, let me state that there is no 'right way' to conduct a mission to Mars. The chosen objectives for the mission, the timeline, and the technology development required to achieve the mission objectives have to be weighed against the economic costs, the sustainability of the program, and the level of risk we are willing to accept. Whether we land directly on the surface of Mars or first send humans only into Martian orbit, the technical challenges and required development are significant. Actually entering and subsequently leaving the deep gravity well of the Martian surface will require a multitude of additional systems and greatly increases the amount of payload that has to be sent to Mars.

Mounting a mission to Mars will require many new systems and associated technology to be developed. Bringing together all of the newly developed systems without prior flight experience would be enormously challenging. Every technological "first" associated with the mission makes it grow in cost and schedule because adding even the smallest detail has to be coordinated with the entire system to understand every interaction and its potential implications. Many of these systems can be developed and demonstrated in an incremental approach closer to home. Having demonstrated systems available before conducting a mission to Mars will lower the ultimate cost and risk of executing the mission. With the continuously advancing mission, these huge challenges could be more easily managed through incremental missions of increasing complexity. This would allow us to build on the lessons learned and technology advances achieved from every mission.

There are many different scenarios or paths to achieve a Martian landing. Determining the right path is what NASA does best. An incremental approach to technology development and flight demonstration allows the technology to be created when needed while being able to leverage all the previous experience and lessons learned to make the next mission safer and more robust. This incremental approach worked for putting the first Americans on the Moon. The Mercury and Gemini programs and the early Apollo flights developed and demonstrated almost all of the systems required to land on the Moon before Apollo 11 ultimately landed.

Question 2a. Is a crewed mission to orbit Mars a necessary precursor to a crewed landing on the surface?

Answer. As mentioned in the previous question, a crewed orbital-only mission is not absolutely needed as a precursor to a crewed landing, but as an incremental step, it would be safer and more cost-effective and perhaps represents the more practical way to go. Space exploration needs to be a continuous journey, comprised of many incremental steps guided by an enduring vision. And that journey should extend well beyond the first human Mars landing, so that these greatest of achievements can be celebrated with the knowledge that the next incremental step will advance the frontier even farther.

Question 3. Please evaluate the sustainability of NASA's exploration program given the current budget trajectory.

Answer. NASA's funding for FY 2012 was well below what was authorized by this committee, as is the amount requested by the President for FY 2013 and the amounts reflected in the FY 2013 appropriations bills that have yet to be enacted. Even with a stable but flat lined budget, NASA's buying power will be effectively reduced by 30 percent just due to inflation through the first flight. This inflation-adjusted budget decrease, as far as I can tell, is what is pushing the first crewed flight of the Orion/SLS out to 2021. The budget to sustain the exploration programs is ever creeping towards the minimum threshold of sustainability, and on its current trajectory will be there very soon. We will then be destined to repeat history, adding to the $21 billion in NASA programs that have been cancelled in the past two decades.

As much as I'd like to be an optimist, I have been in the space business for far too long not to recognize the trend of the current exploration program. And it is not because it is an unsustainable idea. I personally think the SLS is the right capa-

bility needed to return America to the forefront of space exploration and fulfill NASA's charter. However, for some time now and especially since the end of the Space Shuttle program, NASA has seemingly suffered from a lack of an overarching, enduring vision for leadership in space science, technology and exploration. The Administration cancelled Constellation then established new priorities and directions such as landing on an asteroid and funding a commercial space capability consisting of multiple providers—without clearly identifying a supporting market or demand. NASA's human spaceflight program was essentially put in neutral for two years as a result of this churn.

In general, a shrinking budget forces schedules to be slowed down to achieve only the objectives for which you have funding. This makes the objectives you pushed off more expensive to complete as time marches on and your fixed costs remain. The cycle is self reinforcing until the groundswell of public opinion calls for the cancellation, as such a program could appear to be significantly overrun and years behind the original plan, all of which could have been avoided if the funding was provided as promised when the plan was created and directed towards other objectives for which they were originally intended and not siphoned off and re-directed to less critical priorities. This was the major lesson from the Constellation program as reported by the Augustine Commission. The Constellation program fell behind schedule and started to go over budget because the promised funding was not realized.

Question 4. If we continue to see a reliance on stop-gap, short-term spending measures moving forward, what strategies can be employed in lessening the impact of such measures on NASA's exploration program?

Answer. As long as NASA is provided an enduring vision that does not shift along with each new short-term spending measure, I think NASA's exploration program could continue to survive incremental funding measures. Remember, an enduring vision for NASA will also inform the Administration and Congressional appropriators and keep them from making short sighted reductions to NASA exploration funding.

Beyond an enduring vision, I think there are other strategies that could be employed. The first strategy that comes to mind is that the United States should lead collaborative international efforts in future human space exploration. The expense of human space exploration, today, can no longer be borne solely by one nation if we hope to expand human presence beyond low Earth orbit. It is in the best mutual interests of the United States and its allies and partners to pool resources, knowledge, and capabilities for a common human space exploration vision to try and offset government's short-term spending measures.

The international community has shown a willingness to follow the United States' lead, as evidenced by the International Space Station. However, that willingness to follow has faltered as the United States has been unable to provide a consistent direction to our international partners that can withstand budgetary and political cycles. If NASA is given a consistent, focused strategic direction that it can execute, the international community will follow.

The United States should not cede critical strategic access-to-space capabilities to foreign entities in the interest of collaboration. The collaboration should be more bilateral with both money and physical products flowing in both directions. The best opportunities for true collaboration are in-space and Beyond Earth Orbit exploration.

In addition to international contributions/participation to counteract stop-gap, short-term spending measures; clearly defined smaller increments of the overarching exploration plan should be established to create higher probability of successfully completing "bite-sized" steps rather than being financially stretched by the much larger overarching plan. The increments can be tailored to match budgetary constraints and take advantage of contributions by the multiple international participants. However, a very important part of each increment will be selling why it is an important step in exploration, how it supports the overarching plan, and how all participants benefit.

Question 5. Given our exploration and science priorities, if NASA's budget remains on its current flat trajectory, what capabilities should the agency reconsider to free up its resources?

Answer. It is unrealistic to expect that NASA's annual budget can be substantially increased in the near-term, but I believe much of what NASA wants to do can be accomplished with the current budget. Rather than look for more budget, it is more important that NASA establish a focused, enduring vision for exploration and science that integrates international resources throughout and assumes that long-term funding will become the normal appropriation process. This also means that NASA needs to examine how it can right-size its resources and infrastructure to efficiently execute a more focused mission. Preserving every capability NASA has ac-

quired is simply not possible in a constrained budget environment. Just as private industry must adapt to changing customer requirements and budgets, NASA must choose priorities and make decisions on what capabilities should no longer be supported and what capabilities must be retained to accomplish the vision. We must instill NASA with some urgency to make the tough decisions necessary to position them to successfully fulfill the focused, enduring vision.

I would ask that inflation adjustments be considered for NASA's exploration budgets to maintain a flat budget in real dollars. As I pointed out earlier, it is my understanding that a flat budget represents a 30 percent loss of buying power for NASA through the first flight of Orion and SLS. Simply providing adjustments for inflation could reduce the gap between the first flight of SLS in 2017 and, based on the current flat line budget, the first crewed flight in 2021.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. AMY KLOBUCHAR TO JIM MASER

Question. Mr. Maser, you mentioned some of the commercial technological benefits we've already seen as a result of use on past missions, such as heart monitors. Are there already technological innovations coming from the Mars *Curiosity* project that may be commercialized for use in our everyday lives? Secondly, what are some of the foreseen innovations with the potential for commercialization that would come out of human crewed missions beyond LEO?

Answer. First, yes. My company provided the launch vehicle rocket engines that propelled *Curiosity* on its way to Mars and built the nuclear power source that is supplying the uninterrupted power to the Mars *Curiosity* rover for the next decade. The technology and designs used in several subsystems of those rocket engines are now being applied to several clean energy development programs intended for wide commercial use. As much as I'd like to see nuclear powered cars to get my gasoline bill down, I doubt this will become a reality in the near future or at least until we have fully automated driverless cars, which in fact could be a spin off from *Curiosity*.

The innovation that enabled an SUV sized vehicle on Mars to drive using advanced sensing and avoidance algorithms could easily find commercial applications. I can only speculate that some of that wonderfully complicated technology is being used on Google's driverless automobile today and could find it into my car sometime in the future. NASA has been working some "self-healing" concepts to reconfigure electronic systems at the chip level, using something called field programmable gate arrays (FPGA), which previously had been used for circuit prototyping. The NASA team has tested multi-hardware units linked wirelessly together, letting them represent systems such as a Mars lander and rover combinations. The team intentionally set up malfunctions in the multi-unit system and then let the system try first to heal itself by reprogramming its own trouble circuits and, failing that, try to get back in business by firing up backup, redundant circuitry. The next step, if both attempts fail, is for another system in the multi-unit group to pick up the workload of the faltering system. If that second unit fails, then the remaining units pick up the slack. And so on. The key is that all of this repair work and redundancy happens without human intervention.

Although NASA may not have used some of this new technology on *Curiosity,* it likely will in the near future and offer numerous opportunities for commercial spin offs in commercial and remote controlled aircraft, and automotive applications. Even if the *Curiosity* rover technology is not directly being used for this application, I would say the chances are some of the young engineers working on this project were taught at Caltech by the same Professors who double as JPL scientists or taught by a professor who collaborated in some small way. Or perhaps a young student read a paper or saw a demonstration or now future students saw that incredible landing which inspired them to study robotics and science. And they will be the ones that commercialize this investment. It is these intangible affects that are difficult to quantify but are absolutely necessary to drive our economic engine and keep America as the absolute technological leader in the global marketplace.

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