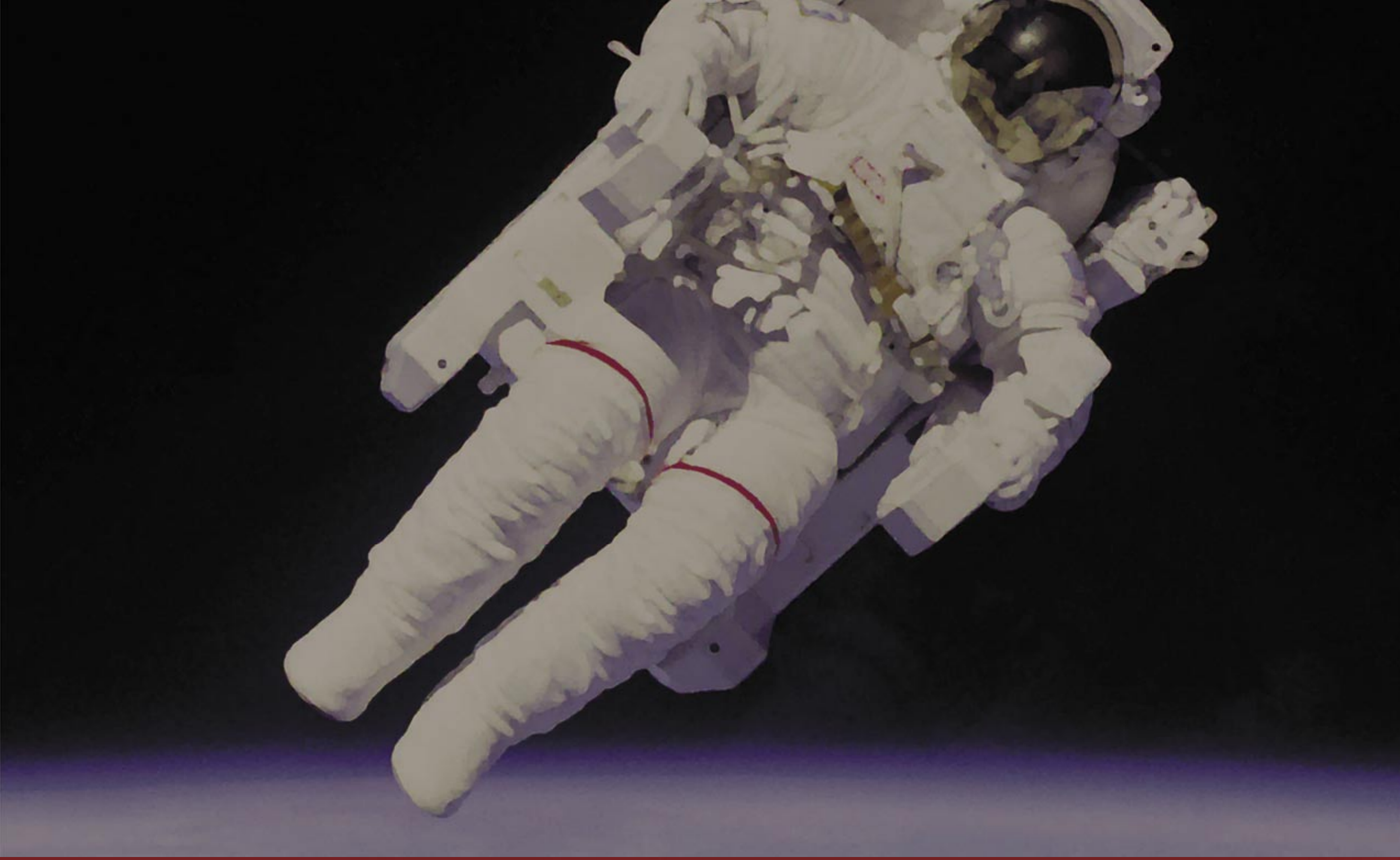

APPENDIX

in closing

NASA Image/Renee Bouchard

Closing Comments

My job mainly right now is to roll the credits and thank a whole bunch of people who made this all happen. Before I do that though, I'd like to take the prerogative of the chair here and just make a few additional comments from things that I'd written down in the last couple of days as well as some prethinking. One is the incredible speed with which we are moving ahead in space exploration. Now that sounds perhaps silly on the surface of it, but think for a moment. In the first 50 years of aviation, a million aircraft were built, most of them used multiple times. In the first 50 years of space exploration, there have been exactly 4500 launches total worldwide.

The difference, the gap, between where we are in commercial aviation today and where we are in space exploration is huge. The fact that Burt Rutan and his group can be so successful today is built on investments that were made, in some cases decades ago, by the government. Now where does this lead us? This leads us to establishing a viable space exploration industry eventually, such that there will be a trailing edge of people who can make a business case and make money out of not only communication satellites, but types of space travel.

Scott Hubbard
Director, NASA Ames Research Center

Scott Hubbard serves as director of NASA's Ames Research Center, in the heart of California's Silicon Valley. Hubbard's tenure at Ames began in 1987 and has included a variety of management roles. From 1997 to 1999, he served as the deputy director of the Space Directorate at Ames Research Center. Prior to his current appointment, Hubbard was deputy director for research at Ames. In March 2000, Hubbard was called to NASA Headquarters where he successfully redefined all robotic Mars missions in response to the Mars failures in 1999.

OPENING PHOTO:
The Space Shuttle orbiter *Endeavour* and its crew of six glide in to Runway 15 at Kennedy Space Center's Shuttle Landing Facility after spending nine days in space on the STS-72 mission, the first Shuttle flight of 1996.
(NASA Image # 96PC-0155)

The two analogies that are already there are the railroads, and, as I said, commercial aviation. The railroads that got the right of way, Union Pacific, Southern Pacific, came together and drove that nail out there in Utah [joining the two railroads]. In aviation, the government invested in mail routes. And, eventually, this form of investment and technology and subsidies led to multibillion dollar industries. I think we are just on the verge of being able to see something like this come out in space exploration, beyond something like the commercial satellite industry. And I think it's going to be an absolutely fascinating journey over the next 10 years or so—maybe it's 5 years, we'll see—as this plays out.

The second major point is to underscore the false dichotomy of human versus robots. The only thing that will happen is the ratio will change over time. And, at some point, a human being, I'm looking at Chris McKay here, will be the tool of choice for exploring the Moon, and, particularly, exploring Mars. If we could put him in a little box, I'm sure he would go with the MSL (Mars Science Laboratory) in '09.

So where do we go with this dialogue? I agree completely with what John said, with what many of you said. This can't be a one-of-a-kind. I think the public will come along if we tell our story well, but we need professional help. Some people say we're beyond help; we need treatment.

But if we can talk about the risk of not exploring, the risk of losing our imagination, and maybe, ultimately, a second home for humanity, I think that we have some compelling things in addition to the kind of spinoffs that may come from what Nathalie Cabrol found by exploring these lakes, that your blood oxygenation goes up, your heartbeat goes down. What does that mean? What does that mean for the biomedical community?

There are a lot of things in there, but telling the big future story, I think, is something we haven't done and we need to do. And we saw some storytellers here in the last few days who just grabbed us. In giving a lot of talks, there's the pin-drop moment, and we hit the pin-drop moment in those places were everybody was just absolutely transfixed by the story.

So, where can we go with this dialogue? One thing is that taking risks can prepare you for the future—often in ways you didn't even think of. I'm going to give you one or two examples from my own experience, which has been largely taking programmatic and technical risks.

In 1975 very little was known about repairing neutron damage in gamma ray detectors. So I conducted, at Lawrence Berkeley Laboratory, a bunch of experiments with a 72-curie plutonium-beryllium source. Now, if you consider that your smoke detector is picocuries, you get some idea of how hot this was.

So, we went through the safety procedures. I signed up to the risks. Twenty-five years later, at the age of 50 or so, I had dual cataracts in both eyes, which was a possible outcome of doing that. But today, Bill Boynton with that same detector orbiting Mars, figuring out where all the water-ice is, is able to repair his detector, because of what we learned doing those experiments, almost 30 years ago, about how you heat the detector and get rid of the neutron damage.

You never know what kind of a risk, and what kind of information, is going to prepare you for the future.

In a similar fashion, in April of 1990, I went in front of the Headquarters folks and proposed the ridiculous mission of using a Delta-2 and a single probe and a cruise stage going to Mars and landing, of all things, using an airbag. The risk there was ridicule and being laughed out of the room, which almost happened. Fortunately, Jim Martin, the legendary leader of the Viking mission, thought there was something to it. And 14 years later, we have now used that technology three times successfully.

So, what I'm building up to is the analogy of setting up the Astrobiology Institute in 1998. We took a risk—and Keith Cowing was part of this—in bringing together an interdisciplinary group of physicists, biologists, mathematicians, astronomers, who never talk to each other. Or if they do, the intersection is only at one point. And saying, let's all think from our disparate points of view about

> IN AVIATION, THE GOVERNMENT INVESTED IN MAIL ROUTES. AND, EVENTUALLY, THIS FORM OF INVESTMENT AND TECHNOLOGY AND SUBSIDIES LED TO MULTIBILLION DOLLAR INDUSTRIES. I THINK WE ARE JUST ON THE VERGE OF BEING ABLE TO SEE SOMETHING LIKE THIS COME OUT IN SPACE EXPLORATION, BEYOND SOMETHING LIKE THE COMMERCIAL SATELLITE INDUSTRY.

a much broader series of questions, like where do we come from, are we alone in the universe, where are we going?

Out of that came a field today, and you've heard references to it, of more than 1,000 scientists worldwide who are engaged in this in everyday research and view this interdisciplinary work, the interaction—the action is at the intersections—as being where we're headed for research in the future. So I would say today, the group that has participated the last two and a half days at this has been at a seminal, similar event of bringing together communities that have perhaps not communicated as much as they should—robotic, human, risk-evaluators, decision-makers. And, so, what we need to do to keep this moving is have the dialogue; perhaps we have a road map, we certainly need a distillation of lessons learned from this, and I would be willing to bet that we're going to ultimately have, if John takes his action items here, thousands of people, maybe tens of thousands of people, who are engaged in doing the kind of work that we got started here over the last two days.

So with that, let me roll the credits and, first of all, thank the idea men—John Grunsfeld, Keith Cowing, the people that had some of the initial concepts for this. Let me thank the Naval Postgraduate School, Admiral Dunne, and, particularly, Chris Walla for hosting us in this incredible venue. It's just been delightful being here. At NASA Headquarters, Bob Jacobs was the lead for pulling this together. Trish Pengra, Al Feinberg, and the inestimable Tony Stewart of NASA TV, thanks to you all.

The group from Ames, from my own Center, Rho Christensen, Danny Thompson, event coordinators. Victoria Steiner and Ed Schilling, public affairs. The video crew—I won't go through all the names. There are many, many people staffing the cameras here, but I do want to mention Jim Taylor and the planners collaborative, Mark Shaddock and Spotlight Productions, Donovan Gates, Donovan Gates Production, and Michael Ditertay and his staff on this 30-person television crew. And out of this will come, I'm sure, an outstanding DVD.

Then there are a couple of other people from Ames that I want to mention—Mike Mewhinney and Kathleen Burton of public affairs, who were part of the advance group getting all this together. Then, finally, a contributor, I'm looking at him right now—one of the real concept, idea, content contributors to this, who through some personal adversity, has managed to stay focused on making this entire thing very successful, Mel Averner. Mel, thank you. Then finally, our moderators—Miles O'Brien of CNN, Chris McKay, Dave Halpern, and again, John Grunsfeld, NASA Headquarters.

So, finally, to wrap it up completely, we want to thank all of you who have spent the last two and a half days with us, and, of course, the honorable Sean O'Keefe, the NASA Administrator.

NASA Image/Renee Bouchard

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Remarks

I had to rearrange my thoughts after going through the day. I had given some time to thoughts about risk and the way we use it and the way we misuse it and all of those things. Well, as the morning went on, the first speaker ticked off the first three or four of my items, and the next speaker came along and fixed them all up. And, so, most of the things that I thought I would like to comment on were gone. Then, just to put the crowning blow on it all, we go in this afternoon and I listen to the most amazing set of people that I could ever imagine. And I'm sitting here listening to this and saying, "Every one of these people, individually, has done more than me and all my friends." Now, how in the world do you get up and talk after that?

Well, I decided that the first thing I had to do was to talk about something different. So, what I would like to do tonight is perhaps a little deviation, but I hope my thoughts are in the context of what you are discussing.

We have a nomenclature issue when we talk about exploration and the word explore: to some people, that means visit planets. To some people, it means do great science. To some

Thomas "T.K." Mattingly II
Former NASA Astronaut

T. K. Mattingly is one of the 19 astronauts selected by NASA in April 1966. He served as a member of the astronaut support crews for the Apollo 8 and 11 missions and was the astronaut representative in development and testing of the Apollo spacesuit and backpack (EMU). He was designated command module pilot for the Apollo 13 flight but was removed from flight status 72 hours prior to the scheduled launch due to exposure to the German measles. He has logged 7,200 hours of flight time—5,000 hours in jet aircraft. A veteran of three space flights, Mattingly has logged 504 hours in space, including 1 hour and 13 minutes of extravehicular activity (EVA) during his Apollo 16 flight. He was the command module pilot on Apollo 16 (16–27 April 1972), was the spacecraft commander on STS-4 (26 June to 4 July 1982) and STS 51-C (24–27 January 1985). After retiring from NASA in 1989, Mattingly continued his work in space science in the private sector, focusing on developing low-cost and reusable launch systems for commercial use.

OPENING PHOTO:
Astronaut Thomas K. Mattingly II, Apollo 16 Command Module pilot. (NASA Image # S71-51295)

of us—I like to call ourselves explorers—but I tell you what, the ride is one hell of a good show. So I think we have different perspectives on what exploring is.

But once you get away from this community of ours, you find that the word takes on a different connotation. We use the expression "to explore business opportunities" and the expression "explore new kinds of things." And, in my mind, this "explore" means to do or to learn something new. It doesn't matter whether it's science or how to manage an organization or how to go places. It's when you do something new. And, in my mind, that can take on something of a different connotation. And so, if you look at it that way, then there are a lot of people in the world that take risks. In our business, we talk about risk and the first thing we think of is some poor kids' young bodies laying there in the ashes.

Well, there are a lot of other risks, and they're very, very real and they're very important. And for those of you that have tried to start a business or have tried to run one with your own money, you understand what the word risk means. And it is just as overpowering as anything else.

When I had an opportunity to launch the Atlas rockets—which, by the way, I consider to be one of the highlights of my career opportunities—I can tell you, it's infinitely easier to sit on top of one of the things that NASA launches, because you are absolutely in the best hands you could ever be and you will never find a lower level of risk. When you go launch it and it's your decision—it's not a committee—you've got investors that you've just assured it's going to fly. But it's the same old rocket hardware and it's just as interesting. And that really gets your attention.

I know that the docs like to record the heart rate—they want to know what Jim's heart rate is at launch and at entry and when he steps around. I tell you what—any of those statistics they collected on us won't compare with making the decision to launch something that's got your money riding on it. That's a different ball game. And it is just as interesting as people.

So, my point is not to belittle people. My point is to say risk is a different thing to a lot of different people for a lot of different reasons. And, so, when we say we're taking an acceptable risk or whatever we're going to do, you have to put yourself in the place of "risk to whom and for what?" One of the speakers this morning reiterated that we all think of risk of life. Okay, that's pretty easy. There is a property risk, but, actually, I think we can take almost all physical property and lump it together under financial arrangement of some sort, except in those rare cases when we're going to use or deplete a natural resource that doesn't get refurbished. I remember one time in the Shuttle program, we just woke up one day and discovered that our demands—if we met the flight schedule—would have depleted the Earth's supply of helium the first year. So we kind of had to do some more engineering. So there is an example of another kind of property that you put at risk. But you also put at risk opportunities, and that's opportunities for you to do something else with your time. The investor could invest in something that's going to come out better—there's a million things that could happen. So the connotation of risk is something that you have to stop and think about.

It seems to me that in a democratic world one of the principles we have is that there are human rights that belong to everybody and we go to great lengths to take care of those. And as school kids we were taught that our rights would end when yours start. Okay? That was an easy principle.

That same thing applies to third parties. When we do our trick and we launch things over people and around them, or when you run nuclear power plants, or when you do all kinds of things, there are innocent parties who did not get to vote on taking a risk. And one has to think very seriously about who it is that has the authority to put in jeopardy somebody who didn't even participate in the decision. One of the nice things about the discussion this afternoon was everybody that I listened to was in activities that did not put third parties at risk. They were responsible for other people, they were responsible for a lot of things, but the innocent bystander was generally immune to their activities. And so that [responsibility to innocent parties] puts an obligation on all spaceflight from the beginning.

John Young (left) and T. K. Mattingly in the recovery raft after the splashdown of the Apollo 16 capsule.
(NASA Image S72-36510)

When we go out of the atmosphere on those missions and come back in, we're going through something that's very traumatic and irreversible. Spaceflight is complex by its nature. It's large in scope and it has a whole range of critical, irreversible decisions in a harsh and unforgiving environment. Other than that, it's a wonderful place. [Laughter]

That first step has got to be right, and with that comes an obligation to all those kids out there in the world that aren't part of our club and aren't having fun doing things that we enjoy. It's easy for us to decide, "Hey, this is good stuff," whether it's good science or just a ball to go do, that's one thing. That's different than saying, "I'm going to fly over your cow pasture and maybe drop something on your house." People tend to get irritated at that.

So, what I wanted to do is step back for just a second and talk about some of the perceptions so that it can help frame the question. Now, I'm not a visionary. I don't know what the world should do—I don't have any idea about whether we should explore Timbuktu or Saturn or whatever. But in my opportunities in life, I've had a chance to do a lot of really neat things where you could have a vision about how to get it done. And so I guess I'm one of those people you call an implementer instead of a visionary. That's what I enjoy doing, and I think that's the kind of things that have just worked out in my favor.

So while not a visionary, I have watched some. What I'd like to do is share with you some thoughts about groups that I have watched and the characteristics of them. Because I'm going to make two assumptions—and these are not debatable, because they're assumptions. I'm going to assume that you either go forward or you die. Civilizations do that. So if you aren't making progress, you're in deep trouble. Maybe it'll take time to play out, but that's the end. And I can't prove that, but, boy, do I believe it.

Somebody gave me the analogy that it's like riding a bicycle. If you try to sit still and not move, it's a very difficult job. And if you can get up a little speed, you can do a lot of things. That's one assumption.

The other I'm going to assume is that there is no way we will not explore the universe. I have no idea what the timeframe is, but one of my investor friends gave me a piece of counsel one day when we were having trouble and couldn't figure out how we were going to make the next step. And he said, "Just don't get in the way of success."

Going back to Jim Lovell's [Apollo 13] mission, there's one lesson that I gathered from our ground risk management and getting a chance to watch the real pros go do that. When we started, within an hour of Jim telling the world he's got a problem, we didn't have electricity, we didn't have oxygen, we're on a trajectory that's not coming home, and we don't have any ideas. And those cats on the ground solved these problems one at a time. The only rule was, you've got a problem to solve, you've got one to solve, and you've got one to solve, and we do have a cutoff date when we need to have all this finished—it was later than Jim wanted it, but it beat the deadline.

But the principle was, don't get in the way of success. Assume that your buddy is going to do his job and you don't want to be the one that's holding up the show. With that, we went through a series of really challenging resolutions to problems. Where folks really didn't know, but they said, "Boy, if they can figure out how to get the water to last, we'll figure out how to get the electricity over there." And it all came together, as you know.

So I'm going to assume that we're going to go do these things and that we're mature enough we recognize that, I think, every success is preceded by a failure. At least in my experience, it's not real clear you can have a success without preceding it with something that's humbling or threatening. Certainly my career has gone through that sort of cycle.

The things we learn, we learn most easily from things that don't work. You've got to be objective, you've got to be honest with yourself, but the things that fail are the things that teach us. I have known a few people who could learn from success, but you know, when you're feeling good, it's really hard to be self-critical. And so you miss a lot of lessons that you could have had. So don't ever be afraid of failure.

So, if that's the case, if my premise is right—we're going to make progress and we're going to go explore—then our job is don't get in the way of success. We don't know from the government side what the funding profiles will be, what the timing is, but we need to be prepared to do whatever opportunity presents. So how do you do that? I don't know. And I certainly wouldn't tell you anything other than sea stories about places I've been. But we're not in those places. We're going forward. And that's a new game and a new set of challenges and new places to go. That means rethink.

So, in that vein, let me just summarize my observations from spending 20 years in government programs and then a few years working as a contractor on government programs and then the last ten years working on commercial ventures. I’ve been in large corporations—government certainly is a large organization, DOD’s a large organization—and I’ve been in some small startups and entrepreneurial ventures. We’ve made mistakes and we’ve had some successes. So I’ve tried to catalog for you the signatures that have shown up in every success. And some were hinted at today and I just wanted to reiterate them.

Number one, you have to have a clear, quantifiable, simple-to-understand objective. Step one. If you don’t fill that square in, don’t worry about the rest of them, because they don’t matter.

Once you’ve got that, you have some more challenges. And it takes creating an environment where getting it right is more important than who’s right. You have to have a group—and big things can’t be done by small groups and by individuals, only by large organizations. The trick in leadership is to create the environment where getting it right is all that counts, because the job’s too hard to do anything else.

NUMBER ONE, YOU HAVE TO HAVE A CLEAR, QUANTIFIABLE, SIMPLE-TO-UNDERSTAND OBJECTIVE. STEP ONE. IF YOU DON’T FILL THAT SQUARE IN, DON’T WORRY ABOUT THE REST OF THEM, BECAUSE THEY DON’T MATTER.

So if you’ve got that, then you have to have competent practitioners. Without that, you won’t go anywhere. Now, back in the Apollo days, that was one thing no one had to worry about. Because if you just said, “Job opening—work on Apollo,” you know, the line went all the way around the county, because it was something every one of the young kids wanted to do.

Today we have to compete for opportunities and people, especially. They will come to an electric environment. The kinds of things that you folks do will draw people. They are there—and they’re the people who want to be there, people who want to be personally accountable.

So in this group, this constellation of things that I have observed as uniform qualities, you have got to have a good objective, you have got to have personal accountability—eyeball to eyeball, participant to participant. That’s not an org chart with lines on it, that’s real-world accountability based on human relations that we have with each other. You have to be competent in your job.

I would caution that one place we’ve gotten trapped is the resume trap or the logo trap. I’m the world’s worst in reading a resume and knowing what somebody can do. I feel pretty good after working with them for a couple of days, and then I know what kind of people I’m around. But I have a real hard time with a resume; they can look really good or really bad.

The logo trap is the other side of that. How many times have we worked in an industry that’s maturing, where the logo of the company is on the wall and it has a record of miraculous accomplishments—year after year they've done spectacular things. All of us, including the employees, believe that we are part of that logo. And it happens at NASA, it happens at any large organization with a history. We identify with that logo, that's a symbol of things that have happened.

Maybe, after a period of time, the people that do those things aren't there anymore. And unless somebody has been very, very careful to be prescient enough to create an honest-to-goodness succession plan, you'll find people who know the language, who look good, but do not have that personal, gut feeling for what it's about that's necessary to do these things that push the envelope. When you find that situation, the places that succeed recognize it, and then they take steps to fix that.

There's nothing magic about this except to face up to the fact that you know what you know and you know what you don't. And with that, those signatures have shown up at every one of these little organizations that I've had a chance to be exposed to.

So, while I can't tell the answers to the next job and the next challenge, because each one's unique, I would commend to you that these observations, that I think I picked up primarily from working at NASA; they have been uniform signatures. We even applied the much-maligned aerospace management process to turning around a very nonglamorous company, where we did a really excellent job of turnaround, coming out of bankruptcy to create some almost embarrassingly good results—done with people in a nonglamorous field and a group that two years ago was absolutely demoralized and hopeless.

It all came from just getting them all on the same page with the right orders. So these are techniques that are not just peculiar to the high-tech business, they work everywhere in life. So that's my observation.

I do have one question I'd like to ask of you. When I was a kid, I lived in Miami, and I used to go down to the beach, like all high school kids, and look up at the sky and see the Moon, and you kind of wondered, "Gee," you know, beer talk, "Hmm, wonder what the Earth would look like [from] up there?" Well, that was too preposterous for even high school kids to talk about. Strange things happen.

I had a chance to go and serve what I thought would be a couple-year tour with NASA, and they were doing this program called Apollo and space-centered life. I knew that when I got there, I wasn't going to the Moon. But, you know, I might be getting in at the right time to go to Mars. [Laughter] Well, that schedule has been modified a couple of times and I said, "Well, okay. I did get to go to the Moon, I hope that doesn't blow my trip to Mars." [Laughter]

Then I woke up and said, "Maybe I could be the program manager to send somebody to Mars." So tonight, I would plead with all of you in the exploration world. Before I turn the lights out, I want to see pictures of people bouncing on Mars. And that's your job. Thank you.

NASA Image/Renee Bouchard

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Remarks

This morning, we heard an awful lot of eye-opening stories about how we are exploring the planet today. I'm awed to be in the presence of so many notable people here in the Monterey Bay Aquarium. Actually, this aquarium has figured inspirationally in motivational movies such as *Star Trek* and other grand works of science fiction. I should tell you I have been motivated by *Star Trek*, I think we heard that this afternoon from Chris McKay.

Preparing for this talk, I continually asked myself why I, of all people, have been asked to speak to you this evening. And I kind of went through the thoughts. Maybe because I most recently returned from space—that seems an obvious one. Or because I've been fortunate enough to survive six flights to space. Or worse, because somebody sees me as prone to avoiding near disasters throughout my life. I know someone in my management chain believes that.

I do not feel I'm a particular specialist in risk-taking or taking risks personally. Rather, I see myself as rather conservative about mitigating risks that I see ahead of myself and my family.

Michael Foale
NASA Astronaut

Michael Foale was selected as an astronaut candidate by NASA in June 1987. He served as a mission specialist on STS-45, STS-56, STS-63, and STS-103. He was flight engineer 2 on *Mir* 23 and *Mir* 24 (ascent on STS-84 and return on STS-86). On his last flight, 18 October 2003 to 29 April 2004, Foale served as International Space Station (ISS) Expedition-8 Commander. The Expedition-8 crew launched from Baikonur Cosmodrome, Kazakhstan aboard Soyuz TMA-3 and docked with the ISS on 20 October 2003. His six-month tour of duty aboard the International Space Station included a 3 hour, 55 minute extravehicular activity (EVA). Mission duration was 194 days, 18 hours, and 35 minutes and, at its conclusion, Foale became the U.S. record holder for most cumulative time in space, having logged 374 days, 11 hours, and 19 minutes.

OPENING PHOTO:
Equipped with a bungee harness, astronaut Michael Foale, Expedition 8 commander and NASA's science officer on the International Space Station (ISS), performs squat exercises on the Treadmill Vibration Isolation System (TVIS) in the Zvezda Service Module, the ISS living quarters. (Zvezda is Russian for "star.") (NASA Image # ISS007-E-17762)

There are many guests amongst us who do not work at NASA, but have very relevant experience in exploration. Please believe that I see risk perception and its mitigation as a rather subjective issue—I think we've heard that a number of times today.

I, and NASA, do not know all the answers. In fact, I feel we may have strayed off course concerning our approach to risk in some areas. We, NASA, need to hear more than anything else not Mike Foale's point of view on risk, but those of people outside of NASA looking in. I feel my job today is to sort of set the scene and issue provocative opinions to you—I mean, I'm opinionated—and you are obliged to dispute them in the coming days.

That said, I'm going to give you my personal view of America's space exploration and the risk that comes with it. But first, I'd like to set the scene for space exploration in the future, inspired by the President's vision for exploration, by showing the first part of a video made within the astronaut office by astronauts and narrated by astronauts—one of whom is myself.

[Narration from video is indented.]

> *Female speaker:* We are, by nature, explorers. Look at the centuries of histories where people were committed to finding new worlds and establishing them. And now I think it's time for us to go beyond low Earth orbit and do the very same thing.
>
> *Female Speaker:* Human beings are insatiably curious. We want to know what's out there in the stars. It's part of who we are; it's part of what we are.
>
> *Male Speaker:* Being outside on a spacewalk is the coolest thing you can imagine—beyond belief. You're doing this important thing, you're building a spaceship and the world is rolling by. It's absolutely breathtaking.
>
> *Male Speaker:* The Space Station is teaching us how to explore. Before we can go to the Moon or to Mars, we have to learn a lot about the human body. What happens when you put yourself inside a spaceship for weeks and even months? What food are we going to eat? Are we going to bring it all in cans or are we going to grow some food on board? What sort of spaceships do we have to build?
>
> *Michael Foale:* When we look back 50 years to this time, we won't remember the experiments that were performed, we won't remember the assembly that was done. What we will know was that countries came together to do the first joint international project, and we will know that that was the seed that started us off to the Moon and Mars.
>
> *Male Speaker:* I think you have to learn to live and work on the Moon first, so you can make mistakes when you're only two and a half days away from a can of beans.

Male Speaker: Human beings can do things that robots will never be able to do. They can anticipate, and they can handle, unexpected problems.

Male Speaker: On the Moon, we ran into about 97 problems that nobody thought we'd run into, and we fixed every one.

Male Speaker: We are going to continue to explore. We can confront the majority of the problems by going to the Moon. And then, building on that will give us the confidence and the technical ability to be able to step further into the solar system and turn our sights towards Mars.

Male Speaker: We go to places where human beings typically can't live because these environments offer discoveries that defy our imagination. We're going to say, "Wow!"

Male Speaker: We want to know where we should land; we want to know where the water is. The robots blaze the trail—provide us with a path to get there. They're finding out whether we could stand on the surface of Mars. Those robots have raised their electronic eyes and given us those first glimpses of the horizon of Mars. To be able to stand on the surface of Mars and feel the wind blowing of Mars's thin atmosphere is going to be a tremendous achievement.

Female Speaker: Can we use some of these resources? Can we prosper here? Can humans live here?

Male Speaker: So far, we have only sent people as far as the Moon, and sent our robots just as far as the edge of our solar system. We are just starting to understand our place in the universe, the perspective that the universe gives us, and the tremendous, infinite variety that the rest of the universe holds. That's where we are headed, and that's where we'll go after Mars.

[Video segment ends]

After watching that video, or others just like it, I find myself kind of naturally responding with enthusiasm and excitement. I kind of go, "Wow!" It makes me feel that we humans can do anything if we agree on a common purpose and simply put our minds to it.

However, evocative and inspirational as my astronaut colleagues can be, we are leaving out of the message something terribly important—risk. Why is that? It's because we feel instinctively, maybe—especially in this year—it will spoil the mood of our message. That it will conjure up very painful and recent memories of lost friends and failed missions.

My theme to you this evening is that we must always talk about risk when we enthuse about exploration. The two are inevitably connected. And I think that message is coming home today.

Risk—what is it? It's obvious when disaster strikes, such as when Shackleton's ship, *Endurance*, was forestalled in his second attempt to reach the South Pole, crushed by the ice while trapped far from his goal. We consider an activity to have risk if a foreseeable outcome has undesirable or dangerous consequences. Everybody knows what risk is, but it's according to their own subjective standards. Risk today, in Western society, might be perceived to be—as T. K. Mattingly referred to—a financial activity or the stock market, allowing your children to take the bus to school, not evacuating in advance of a hurricane warning, or not wearing a seatbelt. And these examples are seen as risks because the consequences can significantly change our lives through financial ruin or loss of life.

So this evening when I speak of risk, I mean the risk of people being killed. Historically, or even today in underdeveloped countries, loss of life was an unfortunate, but commonplace, occurrence within families and all other types of social units. Every child experienced soon in their childhood somebody dying or they saw a dead person. This might have included the ravages of marauding neighbors, war, starvation, and disease.

Before Christopher Columbus, if a proposal of exploration was made—be it to scout the far hills and tribes at a distance, or to utilize substantial resources of the community to send ships on marauding or exploring adventures—the risk entailed would appear to carry consequences not worse, and possibly better than, the risk of inaction.

Inaction might simply mean waiting for unknown peoples to find and attack the community or running out of food or tradable goods. So the imperative to explore then and to take risks then was strong, because the risk was understood widely to be a means to survival and the reduction of future risk.

When a ship that had carried away a large fraction of the able-bodied community did not return or became known to be lost, the news would be just as painful then as it is today, but I think the shock should have been less.

How do exploration and risk play a part on Earth now? I see exploration taking place under the sea, such as underwater archaeology, or on land, such as the search for Mars meteorites in deserts or Antarctica, or in mountaineering—and in space, as we develop human and robotic space missions beyond the realm of Earth. I do not see these combined exploration activities consuming anything but a small fraction of the world's economic and human production.

I do not know how today's activity should be compared to that [of] more than a hundred years ago, but my feeling is that outlays for exploration today represent a smaller fraction of our output than in the past. So, in risk terms, nowadays activities are just as dangerous for participants as any exploration undertaken in history—dying is dying. There has been no change in the fact that people can be injured today and lose their lives while exploring.

What has changed is the public expectation for success, and the public shock when risk and danger show themselves as injury and loss of life. We're not often exposed to death and severe illnesses or injury in our personal lives, unless we're in a group that we could label as thrill-seekers—and we've been avoiding that term here today—or work in medical or emergency services, or in a war zone.

I'm going to show you slides of a series of missions that I did not take part in. I was too young. I was just an enthusiastic, dreamy watcher of these events that took place in the '60s. I'm going to show you astronauts walking out to their vehicle and then the vehicle launching. And I want to tell you to think about how you, the manager sending that astronaut out to the launch pad, might feel—or the family. And then I think about how you, as the astronaut or the risktaker walking out to that launch, might feel about your risk.

[slide] This is Alan Shepherd getting into his Mercury capsule in 1961, May 5th. After the Soviet Union had orbited Yuri Gagarin, April 12th of that year, President Kennedy stated in a press conference, "No one is more tired that I am in seeing the U.S. second to Russia in the space field." And he went on to say,

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"We are, I hope, going to be able to carry out our efforts with due regard to the problem of the life of the men involved this year."

So he did not say it directly, but he was referring to the high risk of putting a human into space. James Webb, the then NASA Administrator, issued a statement no more optimistic. "NASA has not attempted to encourage press coverage of the first Mercury Redstone manned flight." I think that's incredible in today's environment. "We must keep the perspective that each flight is but one of many milestones we must pass. Some will completely succeed in every respect. Some partially, and some will fail. From all of them will come mastery of the vast new space environment on which so much of our future depends."

[slide] This is Alan Shepherd's lift off on a Redstone rocket, flying for no more than 15 minutes until splashdown. The flight was a success. Afterwards, the risk perceived by the public may have been assuaged a touch. But my point to you is, because this was a first flight of a new nature carrying a human, it had great risk. So, like a test pilot, I believe any first flight with a human being carries increased risk, especially in recently designed, new space vehicles.

I'm going to show you a series of slides of space missions, as I mentioned, that I believe carried a particularly high and increased risk. Initially, these missions are ones I did not take part in, and so your opinion is as strong as mine. I think you should hold your opinion and see if it corresponds with that which I'm going to express to you.

In some cases, this risk may have been well understood by the public, such as this first flight of Al Shepherd. Other slides I will show, the public was much less aware of how great the risk was and found themselves surprised. [slide] Here's John Glenn, 20 February 1962, walking out to the first human flight of the Mercury-Atlas vehicle. John Glenn walked out to a much more risky launch than the one before him by Gus Grissom, which had also been on a Redstone rocket. Why? In my opinion, it's pretty clear. Because the vehicle had been changed. The mission was very different. Launched to orbit with 3 times the speed of the Redstone, 10 times the energy to gain getting into orbit, and 10 times the energy to dissipate in excess heat reentering from orbit.

This is the basic fact of the physics of spaceflight into orbit and away from the Earth. The energies needed to be acquired or dissipated are huge, roughly 300 times the kinetic energy of airliners, 290 that of supersonic jets, 25 times that of *SpaceShipOne* this week, on which I, personally, pin much hope, and I think the rest of you do, also.

Was this huge difference compared to Alan Shepherd's flight understood by the public? Kennedy did say only later that year, in September, "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."

[slide] When Gus Grissom and John Young walked out, in March 1965, to Gemini 3, the risks were again increased, in my opinion. It was a new human launch vehicle, a first flight for humans, and it was a new, larger spacecraft, the Gemini capsule. On the previous rockets, there was an escape tower. The crew escape system was reduced in this case—ejection seats—diminishing its capability compared to Mercury. It was a big, risky step for our nation's space program, but probably not perceived [as so] by the public.

[slide] This is Ed White on the first U.S. spacewalk—definitely a new risk in our space program, adding to others as a first-time test.

[slide] Here's Neil Armstrong and Dave Scott docking with the Agena upper stage, only to experience high rotation rates when they docked. They undocked and experienced even worse rotation rates, tumbling. They saved themselves by switching to a different attitude control jet system and made an emergency splashdown thousands of miles from the planned recovery area.

So the risk of human space exploration then, in this program up to that point, had been successful. Shows itself as a real hazard, but in NASA parlance, we call that a close call. It's where we go, "Whew! That was dangerous," breathe a sigh of relief, but nobody lost their life.

[slide] The death of the Apollo 1 crew—Gus Grissom, Ed White, and Roger Chaffee—in January 1967, in a fire inside the command module while on the launch pad, pulled NASA and the Nation up short. But the tragedy brought the best out in NASA and the Nation at that time, with new public resolve and tough lessons learned.

[slide] Two years later, an incredibly bold and risky decision was made by George [Mueller] and others to send Apollo 8 to the Moon after only one manned Apollo flight. Jim Lovell talked about that this morning. I think it is an incredible flight, especially risky because they did not take a lunar module with

them, which, because of its independent systems as a spacecraft in its own right, mitigated for future Apollo missions the risk of command-module failure.

[slide] Apollo 11 was well-perceived by the public to be risky. I think failure would have been tragic, in their minds, and awful, but not a shock. There was the unknown risk of landing on the lunar surface, plus the high risk of the Apollo system as a whole, but, so far, successfully flown. I remember as a young boy of about 12 or 13, the success made me sigh with relief, as if the risk had somehow gone away at that point.

The reward for the United States, for the Nation, when we are willing to take risks and to explore, is really so obvious in lunar rendezvous; the liftoff from the lunar surface with just one engine—only one engine to get you into orbit—carried a whole other set of risks with it.

And then we come to Jim Lovell's flight with Apollo 13. Its emergency was more of a type—in my mind, Jim—that NASA actually expects and tries to plan for. Risk again showed itself as real. I've wondered how I might have felt leaving the Earth when the accident happened.

As he pointed out, it was a fortuitous place—200,000 miles from the Moon—from his point of view. But, in my case, I think of not being able to turn around as the power systems of their command module failed. I think of what the cold, dead spacecraft may have seemed like when I was on *Mir*, when we lost energy, lost power, without a single sound and no power and the cold of space sucking the heat out of the spacecraft and yourself and your crewmates. It's a very, very hard task dealing with a dying spacecraft because it gets so cold and so wet. For Apollo 13, the risk was seen to be a close call. I don't mean to diminish that, Jim Lovell, but it was a close call because we pulled it off—you pulled it off—no one died, thanks to thousands of people on Earth and your crew.

[slide] STS-1, with John Young and Bob Crippen. This was the first powered flight of a Space Shuttle. I feel this was the boldest, riskiest flight in NASA's history. But if you mention that to John, he just seems to mutter some understatement characteristic of only John Young. The launch involved three characteristically different components to work perfectly and all together for the first time in a manned test. These were the external tank, the solid rocket boosters, and the orbiter. And within these, the main components—engines, hydraulic power units, fuel cells—all had to work reliably, but at least these had been tested in an integrated fashion before powered flight. This was not true of all three components together. No unmanned flight of the STS had been conducted. And the buildup to STS-1 was slow and difficult for NASA, so the public heard about its risk in the press as much because it had been so long since the last manned launch of Apollo to Skylab. For all that risk, the crew escape system—ejection seats—was especially limited compared to that of Apollo, adding even greater risk to the crew for this first flight.

But STS-1 was a success, as were subsequent flights up to the 25th, *Challenger*. The ejection seats were removed. Our public and NASA seemed to expect space exploration to be like that of airline operations. And to be fair to the public, this is an understandable misconception.

Only recently—just two weeks ago when I was climbing Mt. Baker—we were discussing the loss of *Columbia* with people who do not work in the space program. And the genuine question goes, "After all, the Shuttle lands like an airliner, right? So it must be as risk-free as an airliner. You spent all that money on it." I've heard this from generally well-informed people in different professions. So the public is especially shocked when the Shuttle is destroyed.

Okay, so why do astronaut applications to NASA actually increase after we've had a disaster, including me in 1981, watching STS-1 from Cambridge, England, driven to become an astronaut. Would-be astronauts do risky things to acquire the skills of explorers—I think Bill Stone overdid it this morning—such as fly gliders or scuba dive on expeditions in Greece; this is something I thought was really captivating and interesting. Or excavating human remains in the low visibility and cold conditions on the *Mary Rose* in the English Channel. There was risk in these exploration activities for me and the two people who preceded me. Two people had died in the course of many dives on the *Mary Rose* [before I joined the] project. But the excitement of discovering new things was compelling and it pushed me to do more.

[slide] Becoming an astronaut in Group 15 in 1987, after *Challenger*. Yeah, you'll recognize some characters here, it's an in-crowd, but it was a result of my desire not to take risk, but to experience space exploration. My desire outweighed the risk I perceived, a risk greater than I probably realized at the time.

[slide] This is astronaut spaceflight readiness training, and it carries risk. We may have to eject out of a T-38 or be picked up by helicopter in search-and-rescue exercises. Or—this is not hazardous—overeat during a survival exercise. But these training activities to prepare astronauts are undertaken to reduce our future risks during space missions.

So our training carries risk also, and this is to be balanced carefully with the higher risks that we are trying to mitigate in the conduct of our space missions. Our remote outdoor expedition training is a key to preparing crew members to make use of local resources, solve technical and mechanical failures in difficult conditions.

[slide] Here John Young and Charlie Duke are being trained in geology to increase the science return of Apollo 16, which was highly successful. I believe we need to place future exploration astronauts into geology field work, in a long-duration expedition context, as part of scientific expeditions where scientists have a stake in these activities of the astronauts. So the astronauts feel the pressure that stake has on them, [as] for example, searching for and recognizing Martian meteorites in the deserts or in Antarctica.

Post-*Challenger*, my first flight was on STS-45 in 1992. And my family took the risk very seriously, as the families of all astronauts do, as did my first commander—Charlie Bolden. And he was already a three-time flyer, I think, at that point. And he strongly encouraged me—and I was a bit surprised by this—to write a will. It was honest advice for a risk-taker from a risk-taker.

NASA managers work to the very best of their ability to manage our risk when we fly, but they are limited to the tools at hand, the architecture of the

Space Shuttle system, and the inherent risk in all launch systems attempting orbital speeds.

In the late 1990s, NASA was directed to work with the Russian Space Agency to build the International Space Station (ISS), providing sustaining financial support to, at that time, a Russian space industry in severe difficulty. And it jump-started the redesign of the ISS and initiated a series of joint Shuttle-*Mir* missions throughout which a NASA astronaut would be left aboard the *Mir* to gain experience in the conduct of long-duration space flight.

[slide] So here a few of us and our Russian support staff are gathered in front of Yuri Gagarin's statue in Star City. As Charlie Precourt and our crew brought me towards *Mir* in 1997, I was anxious actually not about the risk, not for my safety, but my ability simply to interact well with my Russian hosts, my cosmonaut crew. The launch was behind me, and I reckoned the on-orbit phase should be less risky.

Lloyd's of London must have thought the same, because they charged me the same $1,500 for mission life insurance, just as they had for my shorter Shuttle missions. They would have been horrified as that mission unfolded, I think.

The risk of the U.S. working with Russia in the conduct of these expeditions was that the two sides did not, and could not reasonably, know everything about

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each other's decisions and processes. I certainly did not know or understand that well at the time. A lesson learned during this program was that we are obliged to know as much as possible about each other's operations that carry risks.

Jerry Linenger, who I was replacing, happened to tell me in the handover a hairy story about a manual Progress docking attempt, which Vasili Tsibliev had been instructed to carry out earlier and which, in the end, failed, finishing in a close call, a fly by of the station. I listened attentively, but did not know how to calibrate it as a risk. At any rate, I considered the presence of an independent space vehicle—the Soyuz—to be sufficient to insure our lives in the event of bad events on the space station. And, as it would turn out, we came very close to testing my supposition.

I'm going to show you, very briefly, a clip of a collision of a Progress vehicle that took place while I was on board the space station *Mir* in 1997. Before the actual collision takes place in this video, I will show you the way this docking attempt should have taken place. There you will see a Progress vehicle coming in towards the space station, towards the docking axis. And it will dock in a nominal fashion, stopping at about 100 meters, and then the crew takes over, using manual controls.

In this successful attempt, carried out by Anatoly Soloviev and Pavel Vinogradov, that I witnessed actually later on in that year, they were using all of the full capabilities of the Progress docking system—the range and range rate, the radar system—that allow a normal automatic docking to take place. Vasili Tsibliev, my commander in *Mir* 23, had been asked to turn off that equipment—not use it. Why? Because the program in Russia wanted to cut the cost of buying a $2 million electronic box in the Ukraine. That was the rationale for this test. As it unfolded, and as I learned about it, I realized this was a gross miscalculation of what we were ready to do that day, and it was very improperly thought through [about] how to carry out this docking test.

[video] The sound you hear is in the Soyuz as I was flying around in there looking at the damage, actually. This is the docking module that we're talking about—the docking core. Here's Anatoly monitoring the TORU docking equipment. And he sees the *Mir* in his sights as he flies the Progress manually, looking through a camera from the Progress towards the *Mir*.

This now is the scene as Vasili saw it. We'd already gotten too high above the *Mir*. You can see the solar arrays of the *Mir* here, this is the long axis. I snuck this video, by the way, which is why it's such poor quality. They didn't know I took it. And the docking was along this axis, it was meant to be. You can see we're high above the *Mir*. Vasili is not really saying anything in this audio yet. I'm just watching over his shoulder. Sasha is nearby. We should be docking on this axis, but we're now moving this way.

Sasha is saying, "You should move out." Sasha is saying, "Break out! Break out!" He says to me, "Get to the spacecraft." This is my feet coming by the scene here. And then, that's the crash as the Progress hits. At this point, I'm floating into the space towards the Soyuz and the pressure's already falling, I can feel the pressure, in my ears falling.

This is the classic klaxon that you hear when you have a loss of pressure. Afterwards, when we did the survey, flying around in the Soyuz spacecraft, we looked at the damage and we saw that the solar array had been badly crashed.

After big events—after risk—you relax. And I wanted to show you what the handover's mood looked like as we finished up. After that pretty terrible day for Vasili Tsibliev and the rest of us, but particularly bad for the commander who suffered the stigma of this collision, every day we would look out of the window at this scene.

The damage to the Spektr module was serious, and it broke the foundation of that solar array that comes in here towards the Spektr module—so much [so] that I feel that the bearing was the location of the breach in the hull or [the] leaks. And Anatoly Soloviev and I did a space walk in Russian suits to survey the damage and try to find a hole, but we were not successful.

More serious and risky were the successive—and this takes me back to Jim Lovell's experience—times when we would lose complete attitude control of the space station and tumble slowly. When we had isolated that module—the Spektr module, Sasha and I—after the collision, we had cut off 30 percent of the *Mir's* power supply in so doing. And so now, the *Mir* was in a very critical energy state.

Actually, orienting the *Mir* using the Soyuz, which was the way we did this to overcome the loss of attitude control, always made me nervous that we would have inadvertently stabilized it in a spin, so stable that we would forever be stuck in it and direct the arrays away from the Sun and then, therefore, kill the station.

[slide] This is for John Grunsfeld. To put risk on *Mir* in perspective, I have to add that the risk of a Space Shuttle flight, for me, after the *Mir*, was just as real to me. It was while participating in a Hubble repair mission—with John Grunsfeld, by the way, over here—on STS-103 in 1999, commanded by Kurt Brown, that I felt the most anxious about what we're planning to do. And the task simply was performance anxiety for me. To change out the brain, the main computer, of the telescope—that made me more nervous that day, about my own performance and the risk of my actions, than anything I have ever experienced in all of six space missions. To leave Hubble worse off than we had found it, now that was a nightmare I did not ever want to contemplate.

Coming back to Russia again, NASA's experience on *Mir*, I believe, went a long way to reducing risk in working with the Russians on the International Space Station. We gained insight into their commissions and launch decision-making processes.

[slide] So here you see me. I want to show you, this is the management point of view, and it's a serious one of launch readiness. Ten days before launch on that Soyuz TMA-3 in October of last year, I am being presented as kind of an item—Exhibit A—to the Russian commission. Not only as a risk-taker, but as a form of risk mitigation. The argument was presented, in front of me and my crew, by Star City that our training was complete and sufficient and so, therefore, our performance did not represent a risk to the completion of Expedition 8. It was kind of a unique situation to be in for me.

Astronaut Michael Foale, Expedition 8 commander and NASA's science officer on the International Space Station, gives thumbs up after he and his crewmates successfully landed in north central Kazakhstan on 30 April 2004 in their Soyuz TMA-3 capsule. (NASA Image # JSC2004-E-21242)

As we approached the time of departure from Star City to the launch site in Baikonur, Kazakhstan, my family—Rhonda, Ian, and Jenna, and those are my crewmates, Aleksandr Kaleri and Pedro Duque—were toasted very seriously by the Russians and thoughtfully, acknowledging the unspoken risks in front of us as we embarked on Expedition 8. At this point, no one talks about risk.

[slide] I'm going to show you the walk out from the suit-up building in Kazakhstan out to our designated squares, and then the salute, and then on to the launch pad for a Soyuz launch. On the way out to a Shuttle launch, you become introspective, somewhat, as you notice all the other vehicles for a Shuttle launch are leaving. On the way out to a Russian launch, I'm always amazed that in Kazakhstan, when you get to the base of the rocket, you're surrounded by

hundreds of senior figures and VIPs, and they're all clamoring to be there, right next to a steaming, hissing, breathing rocket. I guess they want to take part in the same risk as we three have to at that point in the launch sequence.

At this point, though, they've moved everybody away. The ride is incredible. I don't know how to describe it. There's a lot of rumbling noise, vibration. Very abrupt cutoffs as we go through staging, and then there's peace and quiet when you get to orbit. And all the hoopla you went through getting to the launch pad is kind of behind you.

You think about, if you have a reflective moment, your family back at the launch pad, thousands of miles away already.

If you were to watch the faces of launch teams at Cape Canaveral, and the managers, you would find expressions of concern and nervousness and prayer and hope written all over their faces. At this moment, if people have forgotten the risk of the launch, then they remember it.

On board, it's more simple. Crew members have to only perform reliably and carefully. In my mind, once embarked on a risky phase, be it crossing a crevice field on a glacier or carrying out procedures using dynamic operations in a space vehicle, at that point, you have to stop worrying and move on to minimize the risk of your own failure. That's the risk-taker's point of view.

Of course, there's time to relax sometimes, such as New Year. A long-duration mission is very much an act of endurance and perseverance. The risk I take most seriously is being part of a crew that cannot shift out of relaxation from routine to operational readiness for dynamic operations. An example of that would be shifting to operational readiness for reentry in a space vehicle after you've spent 194 days in space.

This transition for our crew, including a long-time unseen flight engineer, was probably the greatest risk we were exposed to during this otherwise pretty nominal expedition. The ride is incredible. From four hours ago, [when] we were enjoying chocolate and drinks, and then, after a deorbit burn, pyro belts firing, tumbling, the shock of parachute opening, rapid depressurization of the spacecraft, and then the smell of cordite coming in through the vents of the spacecraft into the cabin; finally, you touch down onto the Kazakhstan plain.

[video] He's saying, "I congratulate you." This is the hole made by a thruster made on the Soyuz spacecraft as it did the braking burn.

After the risk is past, crew members, family, space managers, all of us are relieved, and we celebrate how we have cheated death once more. It shows in our faces that the risk of spaceflight and space exploration is always present, and we must always be honest about it, explain it, and do our utmost to reduce it, without hiding it. That way, when we risk-takers are back with our families and we talk about committing to new space exploration—she says, "Don't you dare fly again!" [joking] No, you talk about it. Nobody should ever, ever be shocked if, in taking those steps, we should falter and not return home.

Exploration today carries risk just as dangerous as it did in history. I believe we must honestly explain that risk, just as we move forward to carry out the

President's space exploration vision. Americans can suffer discomfort, hardship, and overcome the greatest difficulties when the goals and risks are laid out plainly side by side. We must take on these most challenging adventures, while looking into the face of risk. In that way, we will achieve some incredible things in space.

You've listened this evening to me and the excellent discussion today.

Please continue to let me and us know what you, the public, and our Congress, think about risk-taking in space exploration. Thank you for being here this evening.

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About the Editors

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