SESSION THREE

stars

Introduction

In this symposium, we've heard from women and men exploring the earth, the seas, and the limits of human capability. We've discussed personal risk, programmatic risk, technical risk, survival of the species risk, and the most important of all, the risk of not exploring at all. We are compelled by some ancient instinct to push the limits, to go where humans can't survive except for brief periods of time or with significant technical support.

My name is John Grunsfeld. I'm the chief scientist of NASA. I'm an astronaut; I've had the privilege to fly four times in space. I've done five space walks, so in fact—along the lines of going to places where people can't survive—I do, in fact, work in a vacuum, along with many of the others in this room. And it's truly a privilege to have been able to be involved at the infancy of space exploration. In this session, we do turn to that ultimate challenge, our first steps off the home planet. We live in a truly remarkable time.

As we speak here, as we're comfortably sitting in this environment, Gennady Padalka, the commander on the International Space Station, and Mike Fincke, the chief science officer, are spending their 163rd day in space. (I may be off by a day.) For over three years, we've had 24/7–365 occupation of the International Space Station. The ultimate service, if you will. And I think that's pretty remarkable.

Spirit and opportunity are still alive on Mars; we'll hear more about that. Cassini is at Saturn taking unbelievable images, things that we've never seen before, things that we certainly don't understand. We have the Hubble Space Telescope, the Spitzer Telescope, and the Chandra X-ray Observatory astronomy facility—three of the four great observatories, all exploring space and discovering things that we couldn't even imagine when these instruments were conceived.

We now know that there are over a 100 planets around nearby stars, when a decade ago, we only knew about our own solar system. And, in spite of this tremendous growth of our knowledge of our home planet, the solar system, and the universe, it turns out from recent observations that we only know a tiny bit about what makes up our universe. Ninety-six percent of the universe is filled with stuff and we don't have a clue what it is.

But I have to say, we're a little bit arrogant. Because when I was a graduate student and a postdoc and a faculty member at Caltech, it was believed that we knew about most of the universe, the history of the universe, the Big Bang and inflation and expansion of the universe. And I thought that most of the great frontiers in physics had been solved and we were cleaning up the details. And, as you heard this morning on the sea, we talk about having explored to the ends of the Earth, but 96 percent is still unexplored. For most of the universe, we still don't have a clue what makes it tick. We are really in the infancy in space exploration. Only 12 people have walked on the Moon, our closest planetary surface, and it's time to leave the cradle.

In all the preceding talks, the central theme has been risk—that's what we're here to talk about. One element that has been discussed, peripherally or centrally, is what I consider to be one of the central issues, which is teamwork. Space exploration sets a new extreme as a team activity. I think we can draw a parallel to Jim Lovell on Apollo 13, the ultimate team of folks 200,000 miles from planet Earth with a pretty terrible problem. And Mike Foale, as he described last night, on the *Mir* space station, an international team also with really tough times. And how the team in space and on planet Earth came together to solve those problems that led to the ultimate success of those missions, the safe return of the crew.

For this session, we've assembled a team to continue this great discussion on risk. And I dare say we have, indeed, put together a team of stars.

John Grunsfeld, NASA Chief Scientist and Astronaut

NASA Image/Renee Bouchard

Risk and Reward in Apollo

One of the things that occurred to me that might be worth emphasizing, relative to other discussions that have already occurred, is a brief summary of the reward that came with whatever risk that was run—personal as well as national—with respect to the Apollo program. Certainly it was conceived in the context of the Cold War, and it succeeded spectacularly. And even some of the émigrés that I've had an opportunity to talk with say that it had a tremendous influence on the confidence of the Soviet leadership relative to President Reagan's Strategic Defense Initiative, in that they believed—maybe more so than many of the people in this country—that we would succeed, because we succeeded in Apollo where they had not.

Secondly, the technology base that Apollo enhanced—I think you're hard put to find any specific item that it created, but it certainly enhanced the technology base. That technology base is available to us still today and has accelerated human progress in so many different ways and in so many different fields.

The cultural and societal legacy is often, I think, forgotten. It was a tremendous confidence-builder among the American people at the time. And, really, as we traveled the

Harrison "Jack" Schmitt
Former NASA Astronaut

Harrison "Jack" Schmitt is a geologist, astronaut, and U.S. senator. He received a bachelor of science degree in science from the California Institute of Technology in 1957 and a doctorate of philosophy in geology from Harvard University in 1964. He was a member of the Apollo 17 mission in 1972 and, thereby, the first and only geologist to land on the Moon. Schmitt served from 1977 to 1983 as a United States Senator (Republican) representing New Mexico. Harrison is a founder and chairman of Interlune-Intermars Initiative, Inc., an organization that advocates the private sector's role in lunar exploration and developing lunar resources. He is chair emeritus of The Annapolis Center (risk assessment evaluation) and an adjunct professor at the University of Wisconsin-Madison, teaching "Resources from Space." Harrison consults, speaks, and writes on policy issues of space and the science of the Moon.

OPENING PHOTO:
Astronaut Eugene A. Cernan (left) and scientist-astronaut Harrison H. "Jack" Schmitt aboard the Apollo 17 spacecraft during the Apollo program's last lunar landing mission.
(NASA Image # AS17-134-20426)

world as ambassadors during the Apollo 17 postflight tour, it was a confidence builder for people all over the world. Now, whether we've lived up to the legacy of that confidence or not is another discussion, but nevertheless, these kinds of projects do have that kind of effect, in that, if we can go to the Moon, then we surely can do some other things. And the answer is that you can if you motivate young men and women to believe it's the most important thing they're going to do with their lives. If you can create that kind of motivation, indeed, you can do just about anything.

And, finally, from my perspective of actually having been on the Apollo 17 mission, the scientific legacy is just unfathomable. It is absolutely a magnificent legacy of Apollo and its precursors that they created our modern understanding of the origin and evolution of the Moon, a foundation that's been built upon by some of you with the Clementine and Lunar Prospector missions. It's something that now relates directly to further understanding of the terrestrial planets, not the least of which are the Earth and Mars. Imagine, once in a while, what it would be if we did not have that legacy of information about the Moon—what kind of thoughts you would be having on Mars based on the information currently coming in? So this, in a very brief way, I think illustrates why the reward was so fantastically important and so much worth the risk that a few people, and the Nation and managers and families, took in pursuit of that goal.

Scientist-astronaut Harrison H. "Jack" Schmitt collects lunar rake samples at Station 1 during the first Apollo 17 extravehicular activity (EVA-1) at the Taurus-Littrow landing site.
(NASA Image # AS-17-163-24148)

What I would like to spend a little more time on today is thinking about the probability of success, which is the inverse handmaiden, if you will, as a measure of risk. A few years ago, in a paper that I'm sure nobody saw that I gave at one of the space conferences in Albuquerque, I tried to deal with the evaluation, in a semiquantitative way, of the various approaches that one might take to return to deep space, and, specifically, to the Moon. As you might expect from my biases, the private sector approach won in that evaluation, but it was on the assumption that there are commercially viable lunar resources—namely, as was mentioned by James Cameron and stimulated by the young man here to my right, the possibility of lunar helium-3 fusion power as one of several potential sources of electrical power that we're going to need over the next 50 years and beyond. If you want the latest lay analysis of what the envelope of financial and technical success is for a lunar helium-3 initiative, I will recommend to you the October [2004] *Popular Mechanics*.

But, nonetheless, clean, low-cost energy is one way that we can solve many of the problems discussed this morning. It is clearly the challenge of this generation and subsequent generations as well. My own estimate is that in order to just provide four-fifths of the world's population with the level of standard of living that we enjoy today, we're looking at 10 to 11 times the amount of energy by 2050 that we consume today per capita. I'm not going to go into that any more deeply, but if someone is interested, I'm sure I could find the paper that would go into it more deeply.

Well, ladies and gentlemen, risk is always with us, as has been made very clear by this outstanding symposium. And there are always going to be people around us, many of them in this room, that are willing to take the risks, whatever they might be, because we can conceive of the rewards. We're human beings, and one of the great advantages we have as a species is we conceive of these kinds of things. In major technological-based endeavors, I have come to the conclusion,

> . . . OUR EXPERIENCE WITH APOLLO AND SUBSEQUENT ACTIVITIES INDICATE THAT YOU NEED TO HAVE MOTIVATING OBJECTIVES THAT ARE ABOUT 10 YEARS APART, PLUS OR MINUS A COUPLE OF YEARS.

studying this over the last 20 or 30 years to some degree, that there really are three dominant, interrelated determinants for success.

We were talking about the probability of success here, which is the inverse of risk. One is the size of the management reserve funding; second is the management experience and flexibility to carry out this great project; and third is a cadre, a reservoir, of motivated young men and women.

Now, first let me address the size of the management reserve of funding. In Apollo, you all know the story—true or not, but it certainly worked out that way—of Jim Webb getting an estimate of what it was going to take to accomplish Apollo and then doubling it and doubling it again, and that was our management reserve. And we used all of it. We didn't go over it, but we used all of it. And the reason a management reserve [is] so important is [that] it enables management, then, to deal with the unknown unknowns and with erroneous initial assumptions that might have been made about the approach to the problem.

Apollo is a good example of where an adequate management reserve brought success. The Shuttle is an example, particularly in the early days, of where an inadequate management reserve caused significant problems. I happened to be in the Senate when Shuttle was headed for its first flight, and in 1978 it was clear that Shuttle was not going to get to first flight without a major influx of funds. The Carter administration, at the time, was not willing to fight for that supplemental budget. I think it was the fiscal '79 budget, if I remember correctly, that needed the supplemental. Until a good friend of ours named Hans Mark was able to push and persuade President Carter that the Shuttle was required for verification of the SALT II treaty, which Carter was very interested in, we were not going to get that supplemental.

But, fortunately, Hans did persuade the President to do that and we suddenly had the White House helping us get the supplemental through a Democratic Congress. I might say that Hans had set that one up a little bit, because the payloads had been designed for the Shuttle and not for ELV [Expendable Launch Vehicle], so he had a pretty good argument. That does present, though, an ethical dilemma, and I don't have an answer for this dilemma. It depends on what you believe the ultimate value and reward of the project in hand will be, in that, if you, in a legitimate analysis, know that you have inadequate funding and continue with inadequate management reserve to take on a new project, should you take it on? Maybe the Postgraduate school here could have a seminar or something on that subject and try to come up with an answer, but I really don't have it. Because I think you can argue that the managers of NASA at the time felt that even if they realized they had an inadequate management reserve of funding, that if they didn't go ahead with the Space Shuttle under the constraints that the Nixon administration established, that we would not have a manned space flight program. So I'll leave that dilemma with you, and maybe you can debate it over the next beer.

Now the second thing, the management experience and flexibility, was certainly epitomized by the NASA management team in place between 1967 and, in particular, in 1968–72, when it really did crystallize and became a team that is to be envied, I think, by all of us. And it was critical to have that kind of team, based initially from the heritage of the NACA, the National Advisory Committee on Aeronautics, and added to by people like Sam Phillips and Bob Seamans and others, who came in and provided that really remarkable team that led us through to success, not only for the first landing, but, also, the success for Apollo as a whole. And, indeed, that team of managers, in particular Bob Gilruth, George Low, and Sam Phillips, made decisions well prior to Apollo 11 in order to optimize the Apollo system so that it could be used for scientific exploration of the Moon. All you'd have to do is look at the decisions that were made. The lunar rover, the Block II Lunar Module, the advanced ALSEP [Apollo Lunar Surface Experiments Package] and, strangely enough, the agreement that we should begin to fully train the Apollo crew, beginning with Jim Lovell's crew, in exploration geology. And the combination of all of that meant that we got that legacy I mentioned earlier of a remarkable scientific return from Apollo.

The third and maybe most important determinant for success is to have that reservoir of young men and women available to apply their stamina and their imagination to the project at hand. Jim Lovell did not mention it yesterday, but Gene Kranz, after the Apollo 13 crisis had been resolved, did an analysis of the average age of people in the Mission Control Center and it was 26 years old. And most of them had already been there for several years. And there was just no question that you've got to have that kind of stamina, that kind of imagination and flexibility and willingness to work as teams, or you probably are not going to be successful.

Now, having said that, I also feel that our experience with Apollo and subsequent activities indicate that you need to have motivating objectives that are about 10 years apart, plus or minus a couple of years. But that's about what I think human evolution has given us in terms of our ability to concentrate for 16-hour days, 8-day weeks for a long period of time in order to make sure that which is to be done happens. So, as we look to establishing a long-term capability for indefinite exploration of our solar system and, eventually beyond, I think we have to still think in terms of how we quantize that period into specific objectives that each generation can identify with and accomplish. Now, with respect to public support and political support, I don't think there's any question that we in the United States believe and will continue to believe—and certainly NASA believes—that visibility and transparency are absolutely essential.

If you're going to have active and sustained political and explanatory support for efforts like we are about, you also need to have a White House deeply committed and involved at basically all levels. There is no substitute in the Congress for an active interest and activity from the White House. Whether it's a Democratic or Republican-controlled Congress, you still have to have that. Otherwise, you just don't get their attention very well.

Now, on the private sector side of things, you need to have investor support. And to have investor support, the most important thing, of course, is to have competitive returns on investment. That is, competitive with other uses of capital. If you can do that, if you can show a path for that return on investment in a relatively short period of time, you have a predictable path for success. In fact, it's more predictable than the government, and that's why we're going to concentrate on that right now. I know what the criteria for success are in a private initiative. I know what they are in a government initiative. But the ones in the private sector are much more predictable. Or you just need to have an angel out there with irrational exuberance. And we're hoping to find one of those one of these days, and we'll be on our way.

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NASA Image/Renee Bouchard

Mir Adventures

John asked me to be on the panel and talk a little bit about personal risk. How do you decide, from a very personal standpoint, what risks you're willing to take? Specifically, to talk about the thoughts that went through my head, when I agreed to be a crew member on *Mir*, in connection with personal risk. It's a fact that a person is born and from the time you are born, you are taking risks. Every single person, every day of their life, is taking risks in one form or the other, and, as you go through life, you are learning to mitigate the risk. What risks you are willing to accept, what risks you are not willing to accept in such and such a case. Well, I'm not going to go back to the day I was born to talk about how I think I learned to accept risk, but I will go back to 1962 when I was 20 years old. I just had graduated from college, I was 20 years old, I had a passion to fly, and I had no job. As you can see, that didn't correlate very well, but I knew that what I wanted more than anything in the world was an airplane that I could fly.

So my father asked me what I was planning on doing, and I said I was going to buy an airplane. And he looked at me and he said, "You've never even bought a car yet! How do you even know how to buy an airplane?" And I said, "Father, don't you worry! It's airplanes we're

Shannon Lucid
NASA Astronaut

Shannon Lucid was born in Shanghai, China, but considers Bethany, Oklahoma, to be her hometown. She graduated from Bethany High School in 1960, received a bachelor of science degree in chemistry from the University of Oklahoma in 1963, and a master of science and doctor of philosophy degrees in biochemistry from the university in 1970 and 1973, respectively. Shannon Lucid was selected as an astronaut in 1978, after spending time as a teacher and researcher. She has flown as a mission specialist in the Space Shuttle on five missions, deploying satellites, conducting scientific observations and experiments, some in a special laboratory built into the orbiter's cargo bay, and spending 188 days working on board the Russian Space Station, *Mir*. From February 2002 through September 2003, Lucid served as NASA's chief scientist at NASA Headquarters in Washington, DC. Lucid remains an active astronaut at the NASA Johnson Space Center in Houston, Texas.

OPENING PHOTO:
Astronaut Shannon W. Lucid onboard the Space Shuttle *Atlantis* as she returns home from her six-month mission on *Mir*, the Russian space station.
(NASA Image # S79-E-5388)

talking about. Aviation." And I said, "Everybody in aviation is absolutely honest, so don't you worry. Nobody will sell me a bad airplane!"

So I didn't have to worry about how to go about buying an airplane or what to look for, et cetera. Well, I went out searching, and I found an airplane. Not a pretty airplane, but it was the only thing that I could get in the panhandle of Oklahoma, and, trust me, this is really true, it was sold to me by an aviation salesman with a glass eye. And he told me it was absolutely perfect and he would show me the logbook he had. It just had a brand new fabric job and so on. I bought the airplane, and the next month the airworthiness certificate was taken away from it, so I was grounded. I thought my life was over.

But life went on. And I did get a very, very valuable lesson. And the lesson I learned was that when you are involved in an activity, just because someone is involved in the same activity and maybe they're using the same words, it doesn't necessarily mean they have the same value system. And when you are working with a team, in the activities that you're in, it's very important to know that the people that you're investing with have the same value system, and that when you're talking about something, you're talking about the same thing.

The other lesson that I learned over the next few years, before I came to work at NASA, was I flew that airplane and I flew other airplanes for several thousand hours. I flew from Alaska down to Central America, and there were always concerns about whether or not you're going to have an accident. If you read aviation reports, it seems that most of the accidents were due, in one way or the other, to pilot error. And the biggest concern that I had was, okay, it's okay if you crash, but I didn't want it to ever be pilot error.

So I didn't want the obituaries to read, "Shannon was so stupid. Can you believe that she took off in that thunderstorm?" And, so, that sort of tempered the decisions that I made. And they are all hard decisions that you make while you're flying. Mainly, the hardest decision is not to fly. And I found that I had a very difficult time doing that, to say no, when I really wanted to go. But, like I said, over the years I learned how to do that.

So I went to work for NASA. And I was very fortunate in working for NASA, because with the Shuttle flights that I was fortunate to fly on, I found that there was a team that had the same values system. And one of the great benefits of flying and working for NASA was working with the people in Mission Control, working with the people at the Cape, because we were all part of a team, we were all working together for the same objective.

So, then the day came when I was asked if I would like to be a crew member on *Mir*. And, of course, I would have said, you didn't need to ask because I've been volunteering for years. But I said yes, and then a friend of mine went up to *Mir* before I did, on a flight to bring Norm Thagard back. And my friend had not been back on earth more than two hours when the phone rang, and my friend said, "Shannon, don't go." And I said, "Oh? Don't go where?" She said, "To *Mir*." And I said, "But why?" And she said, "Because you will be living in a mine shaft for several months, and I just can't picture you living there. So, take my advice, and don't go."

And so that was one input. Another input was, we trained in Star City in Russia, and the week before I was to go back to the United States for three weeks before I got on the Shuttle to go up to *Mir*, I was leaving a movie theater in Moscow which doubled as a church on Sunday morning. As I was leaving there, a lady came up to me who I didn't know, and she said, "Are you the American woman that is going to go up on that tin can?" And I said, "What?" And she said, "I saw on the news. Are you really going to go up and be locked up in a tin can for months with two Russians?" And I thought, well, now, that's a novel way of looking at it. It wasn't quite the way I had been looking at it, and [it] made me think why did I really want to do this, because I really wanted to do it in the worst way.

> . . . THE WAY I NEGATED THAT RISK WAS, I CHANGED THE PURPOSE OF THE FLIGHT IN MY HEAD . . . I TOOK WHAT WAS A PERCEIVED RISK AND I CHANGED IT INTO WHAT I COULD HANDLE.

And there were several reasons. One reason was, because I had had several Shuttle flights, and I enjoyed them very much. I really enjoyed flying in space. And if you have a small piece of cake, a big one would be even better. So I figured that, since I had enjoyed the short Shuttle flights I had been on, I would really enjoy a longer duration space flight.

And the other reason why I really wanted to go was because I was curious. I was very curious to find out what it would be like to live and work in space for a long period of time. I was curious to see how the body would adapt. And I really wanted to experience that.

And the other reason was, as a child I'd always wanted to be part of an expedition. I mean, I read all the books about expeditions and going off and exploring the different places on the Earth. And, in my mind, going for a period of time on a long duration spaceflight on the space station would be the equivalent of going on an expedition. Because I had written to National Geographic, I had written to everyone I could think of, to find out how you could get on an expedition. And it turns out that, basically, you had to know somebody who had some money. And since I didn't know anyone, that option was closed. But this was a chance that I had to experience that. So, those were the reasons why I was so anxious and so eager to go and fly on the space station *Mir*.

Now, while I was on *Mir*, there were other risk factors that came in. One of them came when I was talking to my daughter on the ham radio one day. Anything that I found out of any importance about the program always came to me via friends or family members or the ham radio or whatever. And *then* we heard from the program. And my daughter said, "Hey, Mom, guess what? You're not going to come home when you think you are. You're going to be stuck up there for months." And I said, "What? What are you talking about?" My daughter worked for a contractor that worked for NASA, so she was tied into the chain of gossip. And she said, "They're having some kind of a problem, so don't pack your bags yet, because you're not coming home."

And the first time, as soon as I heard that, I thought, oh my goodness. Because I remembered back to meetings that we had had at JSC [Johnson Space Center], and we had had them for years before, talking about space station. They were the life science meetings about how you should plan a mission. And the gist of it was that you could only go in small increments. We had been in Skylab 90 days, 100 days, but we had to be very careful. We couldn't exceed that. We had to have something like 10 to 20 missions before we could go beyond 90 days. And then we were going to go up to 100 days, and then we were going to go up more. One of these very small increments, getting up to where we could spend a longer period of time.

So my first thought when my daughter told me that was [of] those meetings. And I thought, oh my goodness, in one fell swoop we're going way beyond anything they discussed in those meetings. My second thought was, get real, Shannon, let's use a little common sense here. Because there in Star City you've seen all these people walking around that have been in space for a lot longer than you're going to be up there. And there is nothing wrong with them. And, so, common sense negated what might have been thought of as a perceived risk at that time.

Backdropped against the waters of Cook Strait near New Zealand's South Island, Russia's *Mir* Space Station is seen from the aft flight deck window of the Space Shuttle *Atlantis*. (NASA Image # STS76-713-036)

Now, another risk that I felt before I launched was that I wasn't really sure what I was going to be doing when I got up on *Mir*. And I say that because we had the U.S. experiments that were coming up, the science. But we didn't know when it was going to be there, because it was delayed. And no one was just real sure when it was going to get there.

And the other thing [perceived risk] was due to the complexity of the program. I had never been able to go through the experiment that I was going to be doing end to end. So, thinking about it just before we launched, I thought, you know, I could be really being set up here, because if you go and you weren't able to do the experiments, you look, professionally, sort of bad because you weren't able to get your work done.

But, then, the way I negated that risk was, I changed the purpose of the flight in my head. I was not going up to do the science. I mean, that would have been nice, but that wasn't my personal primary purpose. I thought, the reason I'm going to go, and the reason I'm doing this flight, is because I want to see what it's like to have a long duration flight, and I want to make sure that my crew mates and I get along and that we have a great flight. And I thought, that I can handle. That's not dependent on any payload coming up, or it's not depending on having any procedures.

So I took what was a perceived risk and I changed it into what I could handle. Now the next risk that I thought of was, well, people always ask, "Were you comfortable living up there on *Mir*? How did you sleep?" And the reason why I was comfortable living on *Mir* and went to sleep every night without any problem was because Soyuz was always attached. It gave you a great deal of comfort in your heart knowing that if a problem arose, if there was a fire, a rapid depressurization or anything, you had a way home. You had a lifeboat. You could get in the Soyuz and go home. And that you had an automatic abort mode and that gave you a tremendous feeling of comfort.

Now, there was one other risk that arose, and that was, once we got in orbit, it turns out—and I didn't know this ahead of time—the Russian cosmonauts were going to do EVAs [Extravehicular Activity]. I thought, that's fine, they're going to go out and do EVAs, and I'm going to sit and watch them.

Well, about a couple of hours before they went out to do their EVAs, and actually, they were already in their EVA underwear, the commander called me over and said, "Shannon, quick, come here, I've got to train you, because this is what you're going to do while we're out". And I said, "What? I am going to be doing something?" And then he started rattling off in Russian these long lists of commands that I'm supposed to be putting into the solar panels to get them to move so the station will work properly. So, I'm losing my mind, so I say, "Whoa, whoa, wait, wait, wait a minute! You can't have me doing this, because I haven't been trained and I don't know how to do this". And he said, "Oh it's easy." And then he was rattling it off again. Then I said "Look, it may be easy for you, but I'm just an older American woman. So I need a little bit of help." And I said "I need a procedure". And he said, "Procedure? We don't have any procedures." And that was true, they didn't work off procedures very much. And I said, "I repeat, I'm an American. We work off procedures. I have to have a procedure." And then, because it was close to the EVA, he was getting a little tense, he sort of gave up. But then the engineer said, "Okay, I'll help you." So we sat there and we wrote out a list of the commands and procedures that I was to follow. And then we wrote out how I was supposed to know when it was time for me to do this.

And I mention this because I did feel under a little bit of pressure, because I wanted to do the right thing. And I knew I was under pressure because I had a lot of sweat on the back of my neck about that time. But I took the perceived risk, or took what I felt was a risk, and changed it into something I thought I could handle. I changed it into a procedure. I forced the system into accommodating what I could handle. And so that's how I handled those risks.

So, from a personal standpoint, that's how I looked at *Mir* and handled the risks that I saw. Then the big question that people always ask is, "Well, okay, why do you want to fly in space? You have these risks, so why do you want to fly in space?" I know exactly why I want to fly in space. It's sort of hard to put into words. That's why I put this picture up there, because instead of a metaphor, it's sort of like a "picturephor," except it doesn't really say it all. It's a sunset. And you say, "Okay, you want to fly in space because you want to see a sunset?" Yeah. It's because you can look at the world in a new and a different way. You grow, and it's a huge challenge. And one of the aspects that I really enjoyed about spaceflight is because you're working with a team, you're working with a marvelous team.

Now, being actually in space, being the person that actually goes to fly, you're the person that people see, and sort of the tip of the iceberg that sticks up. But it's this huge team effort that does it, and being part of a team, it enlarges yourself, so that you're bigger than yourself. And it's all of that put together that is the reason why I want to fly in space.

And a further reason is sort of the same reason why I really enjoyed working in a lab, back in the days when I used to be a scientist. You'd work in the lab and you'd work all hours, and then, finally, one day it would happen where you had an idea; you had done the experiment, and then you looked at the data, you saw the data, and you thought, wow! This is something new. You had found a new way of looking at the universe. Then you write your paper, and no one else thinks it's as marvelous as you thought. But, still, you had the feeling that you were able to find something new that hadn't been seen before. You'd seen the world in a new way, and it's sort of the same way when you can express in words in such a way that someone else can understand what you're saying, because you put the word combination in a certain way so that you'd gotten the message across.

And that is all part of the same reason of why you want to go into space, and why you want to explore. It's because you are part of something that's bigger than yourself, and you can get a feel for what it's like to be really creative, and really see the world and experience the world in a new and marvelous way. ■

NASA Image/Renee Bouchard

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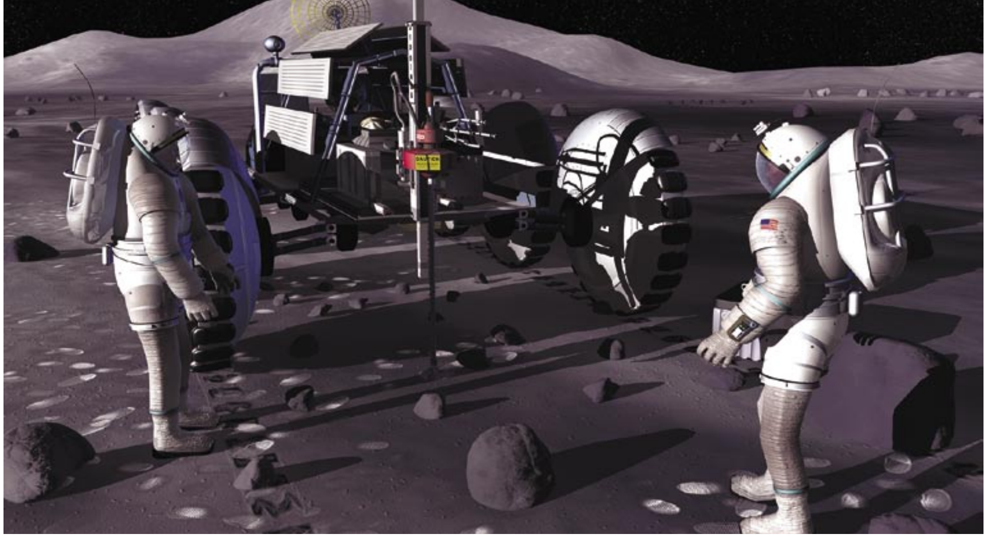

Mars Exploration

I'd like to share with you a very personal set of connected anecdotes to talk about the risk of exploration, in particular of Mars. We all explore in different ways and sometimes we don't know that we're exploring. I think in spirit we explore. In the 1960s, I didn't know the risks I was taking as black disks were hurled at me at 100 miles an hour, and as, in the cacophony of the hockey game, I weighed those risks. And as a young child, I experienced those as well. But I think the message in all of exploration is learning, as one explores, to accommodate the risks, to recognize them, and to react. And, of course, being a hockey goaltender was good training for learning the heartbreaks of exploring Mars.

So, I'd like to try to take you forward a number of years, and the exact date we can't say. But the time when people and machines, women and men and machines, are able to explore Mars. And, in this case, I think the question is really not one of *ifs,* but really one of when the time is right, when those benefits can be matched against the exploration risks. So I'm going to take you through some history to try to talk about that.

I think we all learn to explore in different ways. Shannon gave us a wonderful story of exploring in space. My beginnings in this regard came trying to look for Mars on Earth

James B. Garvin

NASA Chief Scientist for Mars and the Moon

In his position (since 2000) as chief scientist for NASA's Mars Exploration Program and the newly initiated lunar exploration initiative, James Garvin is responsible for formulation of scientific requirements for the exploration of Mars and the Moon and overall leadership of the scientific trajectory of the programs. He began his NASA career in 1984 in the Geodynamics Branch of NASA's Goddard Space Flight Center, Greenbelt, Maryland. He has served as chief scientist for the Shuttle Laser Altimeter experiment (SLA), which flew in Earth orbit twice, and as principal investigator on 12 airborne laser altimeter missions to such remote locales as Iceland and the Azores. He is a co-investigator on the Mars Orbital Laser Altimeter (MOLA) on board NASA's Mars Global Surveyor spacecraft and the NEAR Shoemaker laser rangefinder experiment. He has published over 60 peer-reviewed research articles and thousands of extended abstracts. Most recently (January 2004), he appeared on *The Late Show with David Letterman* as NASA's Mars expert.

OPENING PHOTO:
An artist's vision of future exploration missions: Two kilometers above the lava flows of Mars's Tharsis Bulge region, a geologist collects samples from the eastern cliff at the base of Olympus Mons, the solar system's largest known shield volcano. (NASA Image # S95-01566, courtesy of John Frassanito and Associates)

through the eyes of the Viking mission that I was lucky enough to be an intern for. And in doing so, I recognized that there are a lot of difficult-to-measure things that, in fact, pose risks to the science and understanding we're trying to build. Earth as a training ground was one of the ways in my educational experience that I tried to accommodate risk. But I realized in doing so that there were things I couldn't measure. I didn't have the technology or the tools. Just as many of the explorers taught, I needed more tools to get more data. One way to obtain these data is to benefit from human spaceflight to make robotic measurements.

I realized that the landscapes that we want to understand on Mars and on Earth needed to be measured with new scales, robotic scales rather than human. I was fortunate to benefit from human spaceflight carrying my experiment, the Shuttle Laser Altimeter (SLA), for the first time in the mid-1990s, to measure part of the Earth. This gave me the benefit of human exploration, the Shuttle program, carrying a robotic instrument. The first landfall that instrument made, so to speak, was, rather ironically the path right over Mauna Kea, the truly largest mountain on planet Earth considering the depths from which it rises from the ocean floor. We were rather shocked, in fact, to realize that our flight path allowed us to measure this 4,000-meter place that I had visited as a graduate student some ten years before to learn how to measure Mars.

Now, in viewing human spaceflight to enable robotic experimentation, the same sort of reducing risk routine is important. The advantage of human spaceflight was that it was more akin to flying an aircraft experiment than many of us in the remote sensory arena are experienced with. We had people on site to fix the problems. On our particular flight, in one case, the switch that enabled the high-energy laser to make the measurements was, in fact, wired incorrectly. Human error, part of risk. So we had to command our crews, in this case, to flip the switch off to turn the laser on, and we had a very simple procedure, one step. We were extremely good at it and had we not had that capability, we would not have been able to fly the experiment.

Now, what did we learn? Well, we learned, as we did on Mars, that one of the big side benefits of exploration in the face of risks is the serendipity of discovery from making new measurements. Yes, we measured the shape of the Earth at scales of a few feet from the Shuttle orbit. We told the Shuttle command we were actually giving them orbits within a few feet during flight, which was quite compelling to them. But, we also managed to measure the heights of the vegetation, part of the dynamic carbon cycle of Earth. We had the capability to make measurements of Earth, which we're now making from the ISAT satellite as part of the Earth Observing System, that would help tell us about the carbon cycle on our own planet as we got ready to carry this kind of instrument to Mars to help prepare for landings of vehicles like the rovers.

So, my dream, as I became an explorer off the planet, was to map Mars in 3-D at the scales that humans and others would want to build. The science, of course, was to understand the history of the crust from the evolution of the planet, but also to bring Mars into closer focus, to allow us to make some of the views that allow us to imagine going to places that are very complicated and unique. Without the topographic perspective, learning how to fly into that kind of environment, with robots and then with humans, would have been impossible.

We've learned from the legacy of our forerunners, as we always do in exploration. I think it's important to go back to the Moon, as we are. But it's also important to go back in history to the Moon. Because the Surveyor Program, one of those antecedents built into Apollo, told us many things about the planet, and it was originally conceived as a risk mitigation step, not as a science mission. In the case of Surveyor, they were able to get to new places.

Surveyor 7 took the only picture from the rim of a gigantic fresh crater on the Moon—Tycho. It gave us a new vantage point on the Moon. It helped us look to places we might like to send human beings and understand that great world. These robotic forerunners were the steps that allowed us to get the first successful landings on another world, in this case, on Mars.

> WILL THE RISKS BE ACCOMMODATED TO SEND HUMAN BEINGS? TODAY OUR ROVERS HAVE DRIVEN SPECTACULAR DISTANCES ON MARS AGAINST ALL ODDS. AND YET, IN 20 HOURS WE DROVE MANY TIMES FURTHER WITH A HUMAN SYSTEM. THOSE CHOICES ARE VERY IMPORTANT.

Viking collected 10,000 images from the surface, hundreds of spectra, 14 experiments of the most grandiose nature in the 1970s. Viking's first pictures were not beautiful vistas and landscapes; they were pictures of the feet of the vehicle. They were taken as part of a science contingency plan, the same kind of plan that we, in fact, asked Steve Squyres to implement in sending out his prize rover, Spirit, to Mars. And these pictures actually gave us science, the first views of the sort of fingernail scale or hand scale of Mars. And they showed the fact that Mars dust was kicked up and ended about an hour after landing. So this was science. Viking took science to new extremes in searching for the first chemical antecedents of life and doing other experiments. It also took great pictures. And exploration is about mapping ourselves into a new vantage point.

Now, some of these pictures were high risk. I remember vividly Jim Martin, the project manager, saying, "You're not taking any sunrise pictures. It's too cold. You're not going to do that." Well, we did. Scientists prevailed against all odds. We took that sunrise picture in an attempt to make Mars look the way our eyes would see it. Now, this was very controversial, but it's the way science works. We were trying to understand the Mars that we would see if we were there. That's part of exploration.

Mars has not always been easy. I could go on and on and talk about the graveyard of vehicles on Mars, from our great colleagues in the Soviet Union and our own Mars Observer, the great reconnaissance that we hung our program on in the 1980s. The failed Mars Polar Lander, a wonderful mission. The Beagle, that had the hopes of many to get to Mars. But out of these failures have come lessons—lessons that are the tough lessons of exploration; in this case, with robots before the people.

One of the lessons is that the polar regions on Mars are important. So we've selected a mission called Phoenix, after a year and a half long Olympic-class competition, to go back to recover that science. Likewise, our Mars Global Surveyor, from the ashes of the Mars Observer, has been monitoring Mars and mapping it, enabling landings of vehicles like our rovers. It's important to look at the legacy.

"THE LADDER TO THE MOON WAS BUILT. WE WENT MULTIPLE TIMES, LANDING SIX TIMES. THE SOVIETS WENT AND RETURNED WITH SAMPLES. MAYBE THAT SAME LADDER IS NEEDED FOR MARS."

We built the system for Global Surveyor to operate for one Mars year. That would have been about 9,000 orbits. Today we are over 26,000 orbits. So we were able to mitigate the risk and continue the exploration—just as the rovers are.

So, I think it's important to understand that we mitigate risks by trying new vantage points, to know better, to be more informed. Today, we're building, constructing, innovating, and testing, at Lockheed Martin, the Mars Reconnaissance Orbiter—the ultimate reconnaissance step that will help pave the way for [the] future of Mars exploration. This is a complicated system; it's the largest reconnaissance orbiter to go to Mars in our history. We launch it next summer. It's the team of people that will help us mitigate those risks.

Now, for a minute, I would like to get off Mars. And, yeah, I may be a Martian here, but I think it's important to look at how exploration evolves. As we thought about the planet Venus in the late seventies, we had a vision for a complicated mission to map the planet and its atmosphere. Fifteen years later, that mission is realized in a different way. Thanks to technology, computer science, and information technology, the Magellan mission gave us higher resolution than we had imagined in the '70s, done in a different way. It allowed us to couple what we were seeing from the surface of this hellish world where our Soviet colleagues had landed 12 times [1969–81], to the big picture. This is sort of inverse exploration.

Now, the approach taken by our Soviet colleagues for their brief foray to the surface of the planet Venus, 450 degrees centigrade, was to use an approach that was overdesigned to handle any environment. Overdesign the system to mitigate the risks of the unknown there. Surprisingly, they have not been back since their tremendous successes, which culminated with the Vega landings in 1986. But Venus still offers us a lesson in exploration.

I think the lessons from Mars are several. One is from our own proving ground here on Earth. Here and now, NASA is investing in programs to use Earth analogies, chemical process, laboratory scale analogies, to do science. Likewise with the Moon. The legacy of Harrison Schmitt and Jim Lovell and all those guys that went to the Moon and got those data, is that it is important to move ahead with the Moon as we start to learn about Mars.

Now, I thought it would be instructive to talk for a minute about the differences between the cooperative robotic and human exploration. It's important to remind you of a few facts. Facts are always good when we look at risk. One fact is what we did with the Apollo missions, which I would maintain were at least science enabling, however you choose to look at that. What we did was, we were able to interrogate the surface of another planet, even on foot with minimal tools, in an extremely short period of time. In two days, eight hours of being out on the lunar environment, we traveled two and a half kilometers. That's a human scale of interrogation of another planet. We touched and collected 50 pounds of rocks on the Apollo 12 mission to the Surveyor site. On Apollo 17, we upped the ante. In 20 hours of EVA we drove 36 kilometers.

Today, the pace of exploration is different. It's not different in its yield; it's different in its pace. The question of the timing is one of the important ones as we look at when will the time be right. Will the risks be accommodated to send human beings? Today our rovers have driven spectacular distances on Mars against all odds. And yet, in 20 hours we drove many times further with a human system. Those choices are very important.

Artist's drawing of astronauts setting up weather instruments on Mars. (Courtesy of John Frassanito and Associates)

Today on Mars we've experienced many things. We've looked at small craters in new ways, with robotic assets. We've driven in and are living inside one and yet, we hunger for more. Some craters at the scale of large football fields on Mars actually present tremendous exploration risk challenges. So big that during the Apollo era, the flight rules did not allow the crew to venture into the fresh impact craters of the Moon. Yet today, we have roving capabilities on Mars that could enable that. So it's that cooperative robotic and human exploration that's so important. In my own case, I think visiting impact sites has helped train me intellectually to understand some of those on Mars.

So, as we look at places to go, as we focus our attention on where the people and the machines need to go on Mars, we also need to learn from our experiences. One of the lessons of exploration is the risk of not exploring. Here on planet Earth we have a template for understanding the record of cosmic collisions, but the Moon and Mars offer a better template. It's the template of our history, and yet the opportunities for learning come both here and there. This is one of the learning factors in exploration. The risk of getting there—the trip, going to the places where the action is—can be mitigated by learning about places on Earth that can train us. Training is important. We've heard that again and again. Training with robots here on Earth, people, and then both on Mars.

Finally, I want to relate a story that I think is part of what makes science and exploration exciting. Some of the things we are going for, whether they be supernovae or understanding Mars or aspects of our Earth, are ephemeral. They will be gone. The atmosphere of Pluto is an example we talk about often in science.

I have been fortunate enough to visit a small volcanic island named Surtsey, born 40 years ago. It is already 25 percent gone. It may not survive this coming century, and, yet, it is a little microcosm of how the Earth responds to all the dynamic forces that shape landscapes on Earth. But it's a training ground, too. On this little island operates one of the types of processes that may make the ubiquitous gullies and hillsides on Mars, and we can go visit the island in the same chemical environment as those rocks on Mars. The time-lapse photography has been sped up. Instead of at Mars scale, this is at Earth scale. We can go visit, and, in a period of years, we can watch it evolve, measure [it], and understand how to explore it. We can also learn from new vantage points.

At NASA, it's important to empower the community to competitively seek ways to see Mars in new ways. This last couple of years we had a competition

> ". . . IT'S REALLY IMPORTANT TO NOT WAIT TO WONDER. THAT'S WHAT EXPLORATION IS ABOUT. DON'T WAIT, BECAUSE IT'S IN THE GOING THAT YOU HAVE TO GO."

for the first Mars scout. One of the missions proposed by Joel Levine and his team was to look at Mars from air, to get around more, to do the recon closer to the ground of the Martian system, including the trace gases, that would help us be better informed. Being better informed thanks to reconnaissance has always made a difference in exploration.

So I think there is a set of converging pathways. The timing of the convergence will tell us when the risk can be accommodated to put people on site on Mars for the good of science. There are many pieces, and you can see them. We're doing some of them now: reconnaissance, sample selection with our rovers, understanding the things we see on Earth. Just this summer, I should say austral summer, a field team collected a new Martian meteorite in the middle of the range of Antarctica: a piece of Mars sent by Mother Nature to inform us about what we need to learn about. This collective approach is a way to reduce risk, and, by having a program that does so, we can learn. Where are we going with humans? Well, I hope it's exploring at least, in part, in the name of science.

I will finish with two minor quick thoughts. One is that sometimes exploring is better captured in the eyes of the artists. Georgia O'Keefe, at the dawn of the space age, painted a great picture, *The Ladder to the Moon*, from her vantage point in New Mexico. I think it was Taos. It was kind of an interesting flight approach to getting to the Moon that only a modernist could do. But, I think it is the epitome of the inspiration that allowed us to actually achieve that vision. The ladder to the Moon was built. We went multiple times, landing six times. The Soviets went and returned with samples. Maybe that same ladder is needed for Mars.

So, as we have all said during this conference, it's inspiring and, in fact, more than inspiring, catalyzing the youth to tell us how to go that's important. I think perhaps all the vision we talk about is a powerful risk mitigation tool.

I will leave you with one last thought as best I can. I was giving a commencement address to Thomas Jefferson High School in Virginia this last June. The students were really empowered. They wanted to do space exploration. They cheered when they saw a NASA person show up. I was stunned. I thought there was a rock star somewhere, and I couldn't imagine they were cheering for NASA. I thought, Wow! Here are five hundred of our best and brightest boys and girls wanting to do this. I stared at them, and, rarely for me, I was brought to a lack of words. I stopped a moment, then said, "You know, it's really important to not wait to wonder. That's what exploration is about. Don't wait, because it's in the going that you have to go." So we mitigate the risks by going and not waiting intelligently, and that's what we're doing now in our Mars program.

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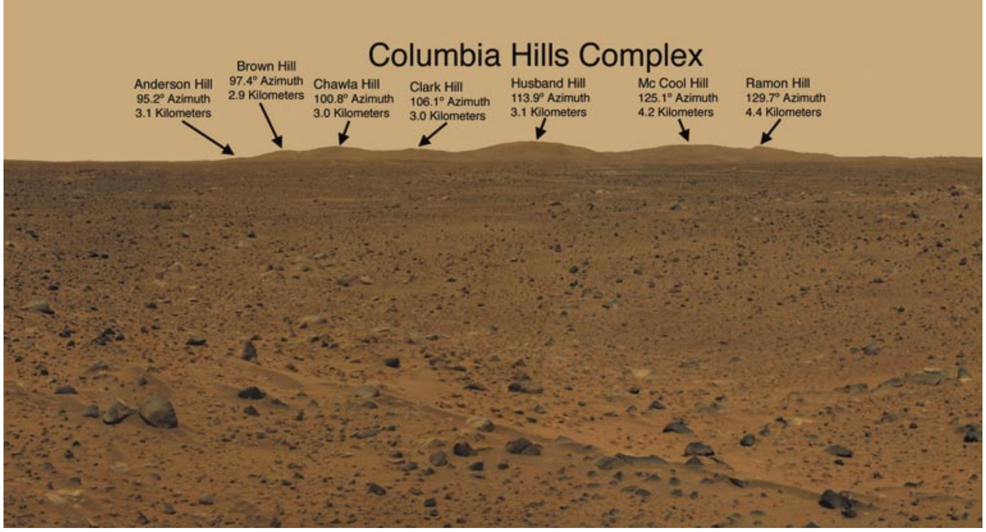
NASA Image/Renee Bouchard



Mars Exploration Rovers

I'm here today to talk about the Mars Exploration Rover (MER) mission, the mission of Spirit and Opportunity, and the risks that we took with that mission. I think by any standard, MER has to be looked at as one of the riskiest and one of the most complex robotic missions that NASA has ever undertaken, but it has been successful. We talked yesterday about mountaineering. Well, Spirit is now the first Martian robotic mountaineer, ascending the Columbia Hills. We talked this morning about oceans, and Opportunity is now exploring the remains of an ancient salty sea on Mars. Penny, I'm sorry, we haven't found any caves yet. Caves are kind of scary places if you're a solar-powered rover. So, we're probably going to stay away from those.

I'm going to talk about the risks that we took to make that success happen. There is one point I have to make from the very outset. It is so obvious that I almost don't need to say it, but it's also so fundamental that I have to say it. That is, there is a very, very fundamental difference between our mission and most new missions we are talking about here. When our rockets lifted off from Cape Canaveral last summer, our lives were not on the line. Now, there were a few meetings at NASA Headquarters where I wasn't quite so sure

Steve Squyres
Professor of Astronomy, Cornell University and
Scientific Principal Investigator for the Mars Exploration Rover Mission

Steve Squyres is the scientific principal investigator for NASA's Mars Exploration Rover Project. He received his Ph.D. from Cornell University in 1981 and spent five years working for NASA at their Ames Research Center before returning to Cornell, where he is now a professor of astronomy. Scientific research for which he is best known includes study of water on Mars and of a possible ocean on Jupiter's moon Europa. He has participated in many missions of planetary exploration, including the Voyager mission to Jupiter and Saturn, the Magellan mission to Venus, the Mars Odyssey, Mars Express, and MRO missions to Mars, the NEAR mission to the asteroid Eros, and the Cassini mission to Saturn. Squyres has served as the Chairman of NASA's Space Science Advisory Committee and as a member of the NASA Advisory Council.

OPENING PHOTO:
NASA dedicates Mars landmarks to *Columbia* crew.
(NASA Image # PIA05200)

about that, preceding launch! I almost feel like I don't belong up here with people like Shannon and with [Harrison] Jack Schmitt, but I think that our experiences do have much to say about how one takes risks in spaceflight, including human spaceflight. There were many aspects of our mission that are in common with what goes on in human spaceflight. We had a very challenging schedule. We had a very daunting technical task. We had an enormously large and complicated team to pull it all off. Addressing and aggressively mitigating the risks that come with all of those things is something on which we spent an enormous amount of time, and I think some of our lessons there do carry over to the very demanding realm of human spaceflight.

As Jim alluded to, our mission arose out of catastrophe. In 1998, NASA launched two missions to Mars. The Mars Polar Lander began its entry and descent sequence and was never heard from again. The most likely cause was determined to have been a single line of code that was missing that resulted, ultimately, probably, in the vehicle shutting off its motors about 40 meters above the ground and hitting the surface at about 50 miles per hour. Then, in reverse, the Mars Climate Orbiter was lost when a mix-up over English and metric units resulted in flying the spacecraft into the atmosphere and burning it up.

So, we were put in a position, which we all embraced from the start, of being involved in a mission that had to succeed. The credibility of a substantial portion of the Nation's space program and some of the institutions involved was very much riding on our success or on our failure. We had to come up with ways to address that risk that were commensurate with the expectations that had been forced upon us by circumstances.

This stunning image features the heat shield impact site of NASA's Mars Exploration Rover Opportunity.
(Source: http://photojournal.jpl.nasa.gov/catalog/PIA07327.)

As with any program, we addressed, and had to face, a wide variety of different kinds of risks. There was cost risk. There was programmatic risk. There were technology risks and environmental risks. There were operational and scheduling risks. I am going to address each of these briefly in turn. There were many things we did individually to mitigate each of those risks, but I think, almost above all, there was one thing we did from the start that addressed every single one of those risks. I alluded to this briefly in some remarks that I made yesterday. We knew what we were trying to do. We had a set of level-one requirements. They were negotiated with NASA Headquarters. They fit on a single piece of paper—two sides. They stated succinctly and clearly what the MER mission was expected to do. From the day that NASA said "go" to the day that we had a date on Pad 17A at Cape Canaveral was 34 months. We would not have made it had we not all had a clear, unambiguous, common understanding of what it was we were trying to accomplish. Those level-one requirements were our guide star.

I lost a lot of sleep wondering whether or not we were going to make it, but I never once questioned what it was we were trying to accomplish. We never had an ounce of uncertainty in our minds. That was tremendously enabling, because every time we faced a decision we turned to those requirements Do we do this test? Do we not? Do we include this component? Do we not? Does it help us meet the level-one requirements? If so, yes. If no, it's expendable. And it was that simple. I don't care how big or how small the organization, how complex or how

> SO, WE WERE PUT IN A POSITION, WHICH WE ALL EMBRACED FROM THE START, OF BEING INVOLVED IN A MISSION THAT HAD TO SUCCEED.

simple your task, I cannot overstate the importance of clear, unambiguous goal setting. It gives a crystalline clarity of purpose to your organization from top to bottom if everybody knows, with no ambiguity, what you are trying to achieve. That was fundamental to our success.

I am going to go through those risks that I listed.

Cost risks: When you get right down to it, our fundamental approach to cost risk was that, when we needed more money, NASA gave it to us. We originally costed the mission out at $688 million. We overran that by more than 100 million bucks. The reasons for those overruns are interesting, and I will be glad to tell any of you about them. They fundamentally had to do with some in-going assumptions that turned out to be flawed. Twice over the course of the development, Firouz Naderi, the program manager at JPL [Jet Propulsion Laboratory], and Pete Theisinger, our very able project manager, and I had to get on a plane and go back east and tell them we needed 50 million dollars more. The first time we did it, we were flogged. We then got our 50 million, and we promised never to come back again.

How long was it, Jim? About six months later, we were on your doorstep again. We were really flogged on that one. When it came right down to it, with so much on the line and so much at stake, the Agency was able to look at their priorities and say, "We have to make this work." Never once over the entire course of the MER development did we not do something important, something that was enabling of meeting our level-one requirements, because we didn't have the money. It never happened, and that was because the Agency made the commitment to make sure it never happened.

Programmatic risk: Programmatic risk means a lot of different things to a lot of people. I will define it rather narrowly to mean the way in which you interact with other programs over issues like personnel, facilities, and so forth. Our approach there, to be honest, was very much like our approach to cost risk. What we needed, we got. The Jet Propulsion Laboratory is an immensely talented, immensely capable organization, but their resources are not infinite. Whenever it came down to something critical—if we needed the right people, we got them. If we needed certain facilities, we got them. There just weren't any questions asked.

The team that was put together under Pete's leadership at JPL was the best that the Jet Propulsion Laboratory had to offer. Lab management always gave us everything that we needed. You can't do that for every project, obviously, but it is a matter of having your priorities straight. Your priorities were that MER had what MER needed, and what MER needed, MER got. There was a phrase around JPL that I heard about. Somebody would say, "I got MER'd". That meant that their facility or their engineer or somebody had been stolen away by MER to go off and make sure we got to Mars okay.

Technology risk: Our approach to technology risk is, basically, don't take any. Our mission was assembled almost entirely from existing, tested, proven technology. Air bags have been used on Mars, parachutes have been used on Mars, aerogel had been used on Mars. The payload was ready to go. The entire mission was put together from existing, qualified, capable hardware. Our computer was a smoking hot machine in 1985, okay, but it was good enough to meet the job that was laid out in the level-one requirements, and so that was what we used. You can sometimes accomplish extraordinarily innovative things by taking all the existing technologies and combining them together in novel ways. And I think there may be a lesson there; I don't think MER is the only opportunity out there for taking existing, proven, safe technologies and combining them together in ways that haven't quite been attempted before.

Environmental risks: This is a big one. There were many environments over the course of our flight over which we had little or no control and for which we had to do our best to prepare ourselves. Launch was an environment that was, as a spacecraft team, outside of our control. That was risky. Landing was certainly risky. Unless you have a fully deterministic landing system when you land on Mars, I don't care how much testing you do—you cannot build a perfectly safe Mars lander. You can build the best system you can, but you can always have one sharp pointy rock or one gust of wind that does you in, if you got unlucky that day at the landing site.

And so our approach to environmental risk was absolutely the best one that you can take: we built two of everything. Two rockets, two landers, two rovers, two payloads, identical up and down the line, but we built two of everything. This is a risk mitigation technique that does not carry over, obviously, into the realm of human spaceflight—you can't say, well, let's send two crews and maybe one of them will survive.

But if you have a robotic mission that must succeed, if you don't send two, you're crazy, in my personal opinion. It worked very well for us. And I'll also point out that it worked very well for the people who were involved in Mariner 3 and 4—Mariner 4 being the first successful Mars flyby, Mariner 3 going in the drink. The same is true for Mariner 8 and 9—the first successful Mars orbiter, when Mariner 8 went in the drink.

There's another aspect of environmental risk, which I think was not adequately appreciated by most people, and that had to do with risk to the science. We were going into a fundamentally unknown scientific environment. We did the best we could to select good landing sites, but we didn't really know what to expect. And one of my greatest fears when we actually first proposed MER to NASA as a single rover mission was that we would choose badly, that Mars would fake us out, and we'd get down on the surface and the science that we were seeking just simply wouldn't be there. If you had two rovers, and if you had a very diverse planet, as Mars is, you could send them to two very different sites, and maybe one of them is going to turn out to be the miracle site.

Mars did fake us out, by the way. If you had told me ahead of time, "Steve, one of the rovers is going to land on volcanic rocks and one's going to land on sedimentary rocks," and you'd said, " Gusev, Meridani" I would have said, "Yeah, sure. It's got to be volcanic rocks at Meridani and sedimentary rock at Gusev." It was the other way around. Mars completely faked us out. And the beauty of having that redundancy to mitigate that science risk is that if it really pays off and both vehicles get on the surface, you take advantage of that diversity to essentially double your science return, because you're in two completely different environments.

Operational risk: The chance that, when you try to do it, it's not going to work. There's no magic formula here, this one's really straightforward. You do it with margin and testing. Now, it's just down to block and tackling on this one. You build a lot of margin into your design and then you test and you test and you test and you test. And like I always say, you test it like you're going to fly it, and you fly it just the way you tested it. And we did a hell of a lot of testing on MER. Our schedule was all about testing. Everything that we did was about testing.

And in the end, those operational risks that we personally took paid off, and the margin in particular was very important. We put a lot of margin in the design—there's margin tucked away in so many nooks and crannies in that design you can't believe it. And it was that margin that made us comfortable signing up to a set of level-one requirements that says this vehicle will last for 90 Martian days on the surface. But if you've got that much margin in your pocket and a few things break your way, you might still be driving around on SOL 265, which is, I think, what today is. So margin pays off in big ways.

Finally, *schedule risk*: This was the worst risk that we faced, by far. In a very real sense, the entire story of the development of the Mars Exploration

Rover program—the development of Spirit and Opportunity—is the story of an extraordinary group of people facing schedule risk. Like I said, NASA said, "Go, and you've got to be there on the pad in 34 months." That was not enough time. It was not enough time. There were many things that we did to mitigate schedule risk—I cannot discuss them all. I will only mention two of them.

One of them—this will sound paradoxical, but it is not, and if you take anything away from what I have to say today, please get this point. Our schedule risk was mitigated to a great extent by the fact that we were flying two vehicles. That doesn't sound like it makes sense. It should be easier to build one than to build two. Well, under certain circumstances, if you're starved for people, starved for facilities, starved for money, then, yeah, that's true. But if you've got the people, if you've got the facilities, and you've got the money, then it helps to be hardware rich. You have more pieces on your chessboard and it puts you in a stronger position. Just as one trivially simple example, there are many tests that you run on vehicles like this that only have to be run on one of your two vehicles. And if you've got the facilities and you've got the people, you run those two tests—not in series, but in parallel, and you take up schedule. And we did that again and again and again and again.

And Matt Wallace, who was the manager of our ATLO—assembly test and launch operations—was a master. He was a hero of this mission and he played that game with those chess pieces with such intricacy and such skill that we made it, and I don't think we would have made it to the pad if he'd had only one vehicle. I think we had to do it with two.

The other way in which, I am somewhat ashamed to say, that we mitigated schedule risks is that we pushed an extraordinary group of people too hard. We pushed them beyond reasonable limits. It damaged people's health. It damaged people's relationships with their loved ones. We got away with it because we had an extraordinary group of people under an extraordinary group of circumstances, but that is not a sustainable approach to Mars exploration. You cannot go back to that well again and again. I do not believe that 34, 36, 38 months is enough time to do a robotic mission of that kind of complexity. I think you need 48, and I hope that lesson is one that is taken away from the MER mission.

I'd like to finish this on a slightly lighter note by telling you a story. We had a lot of discussion yesterday about humans versus robots. And as the robot guy here, I want to tell a story about the experience that I had that really taught me a lot about that particular topic. We were at first trying to figure out how to use a set of rovers on Mars to really do scientific exploration. The technology folks at JPL [Jet Propulsion Laboratory] built a wonderful little vehicle called FIDO. And FIDO was a great test rover—you could take it out in the field and you didn't worry about getting a few scratches in the paint.

We took it out to a place called Silver Lake in the Mojave Desert about 1997. And we went out there and it was the first time I had ever been out in the field. So I went out there with my team—a bunch of really high-priced geologic talent—some serious field geologists. And we got the rover out there and, of course, the rover breaks down. First time I've ever been out in the field, it's dusty, it's dirty, you know, the rover's not working. So okay, what am I going to do with all these bored geologists I've got on my hands? So I said, "Look, let's go on a geology walk. Let's go on a little field trip." So everybody got their boots and their rock hammers and their hand lenses and everything. And I picked up a notebook and a stopwatch. And we walked out to a nearby ridge where I knew there was some interesting geology exposed and we sat down—or rather I sat down—and they went off and they started geologizing.

". . . WHEN I HEAR PEOPLE POINT TO SPIRIT AND OPPORTUNITY AND SAY THAT THESE ARE EXAMPLES OF WHY WE DON'T NEED TO SEND HUMANS TO MARS, I GET VERY UPSET. BECAUSE THAT'S NOT EVEN THE RIGHT DISCUSSION TO BE HAVING. WE MUST SEND HUMANS TO MARS. WE CAN'T DO IT SOON ENOUGH FOR ME."

And I started timing them. You know, how long does it take for Andy Knoll to walk over to that rock? How long does it take Ray Albertson to pick that thing up and break it open with his rock hammer and look at it with a hand lens? And they were doing a lot of things that our rovers couldn't do, but I focused on the things they were doing that our rovers could do. And, you know, I did it as quantitatively as I could—this was hardly a controlled experiment. And when I looked at the numbers afterwards, what I found was that what our magnificent robotic vehicles can do in an entire day on Mars, these guys could do in about 30–45 seconds.

We are very far away from being able to build robots—I'm not going to see it in my lifetime—that have anything like the capabilities that humans will have to explore, let alone to inspire. And when I hear people point to Spirit and Opportunity and say that these are examples of why we don't need to send humans to Mars, I get very upset. Because that's not even the right discussion to be having. We must send humans to Mars. We can't do it soon enough for me. You know, I'm a robot guy. I mean, I love Spirit and Opportunity—and I use a word like "love" very advisedly when talking about a hunk of metal.

But I love those machines. I miss them. I do. But they will never, ever have the capabilities that humans will have and I sure hope you send people soon. ■

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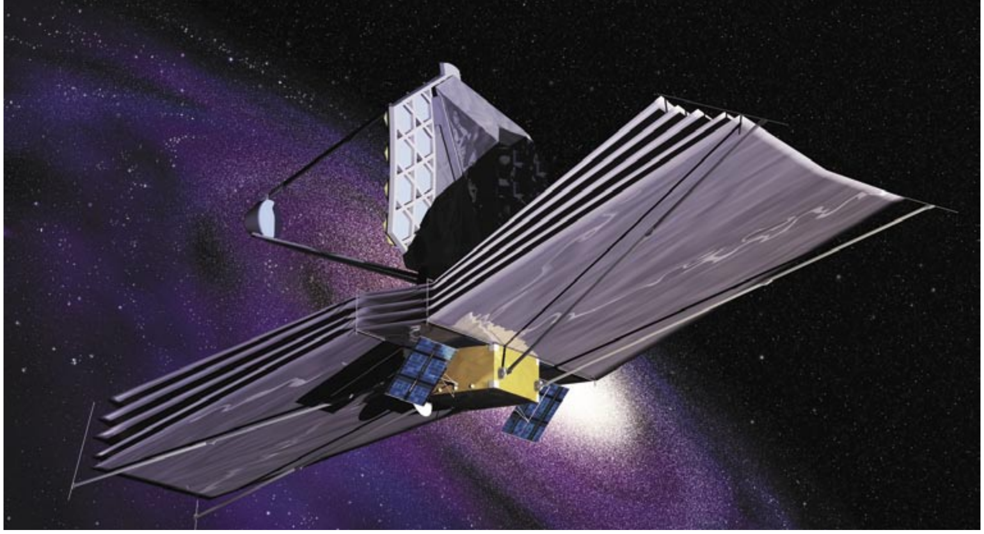
NASA Image/Renee Bouchard



COBE and the James Webb Space Telescope

I want to talk to you about the Cosmic Background Explorer (COBE) satellite and the James Webb Space Telescope (JWST), to give you examples of two extraordinarily risky visions that I have worked on. One of them hasn't been launched yet and one was launched some time ago. So the concentration is on the James Webb Telescope, which used to be called the Next Generation Space Telescope. We had a lot of Trekkies at Headquarters and they were very proud to name it the Next Generation Space Telescope. It was renamed after NASA Administrator James Webb. I didn't know much about James Webb until I read a biography of him and he was in fact a remarkable person and it's a tremendous honor for the telescope to have his name attached to it. If you want to know more about it, there's a book called *Powering Apollo*. It is really very inspiring to read and also points out that he was really very interested in reducing risk by adopting and learning about new methods of management.

And management, I think, is our biggest risk in many areas. Many people have spoken before about losing concentration on the risks that we face and panicking in the dive or whatever it might be. We have to sort of keep the same focus all the way up to top of the management chain, otherwise we get in trouble.

John Mather

James Webb Space Telescope Senior Project Scientist, NASA Goddard Space Flight Center

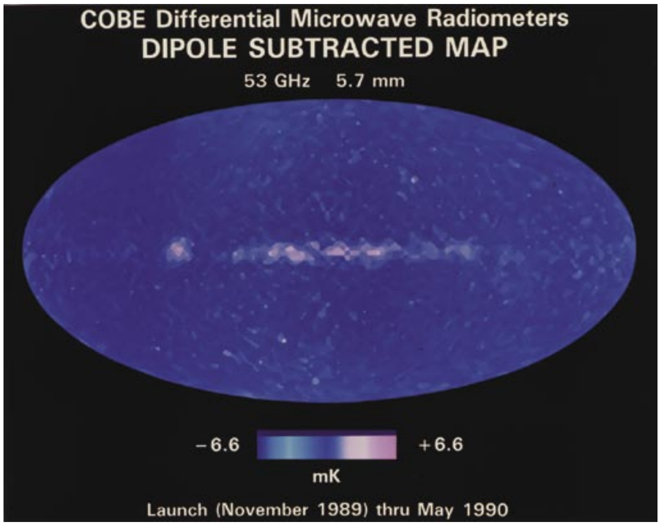
John C. Mather is a senior astrophysicist in the Infrared Astrophysics Branch at NASA/Goddard Space Flight Center. His research centers on infrared astronomy and cosmology. As an National Research Council postdoctoral fellow at the Goddard Institute for Space Studies (New York City), he led the proposal efforts for the Cosmic Background Explorer (1974–76), and came to Goddard Space Flight Center to be the study scientist (1976–88), project scientist (1988–present), and also the principal investigator for the Far Infrared Absolute Spectrophotometer (FIRAS) on COBE. He showed that the cosmic microwave background radiation has a blackbody spectrum within 50 parts per million. As study scientist (1995–99) and project scientist (1999–present) for the James Webb Space Telescope, he coleads the science team with Peter Stockman (STScI) and represents scientific interests within the project management.

OPENING PHOTO:
An artist's impression of the selected design for the JWST spacecraft. (Image copyright European Space Agency)

So, what do I think risks are? There are a lot of things that people call risks that aren't, to my way of thinking. Some things are intrinsically chancy, you couldn't possibly predict whether they would or would not happen. And we have done a lot of things to reduce those risks by working harder and harder on what you can control and predict. But, also, there are a lot of things that depend on who's working on it, who's thinking about it, who's paying. And if you're the management paying to reduce risks and you have another person breathing down on you saying, "If you spend any more money on that project, you're out," there are a lot of kinds of risk that people feel and take.

So why should we take risks? Well, exploration and science are always about the unknown, and that's intrinsically the nature of it. So that's why we're here.

The first project that I did was a mission to measure the primordial cosmic microwave background radiation in a couple of different ways, and to look for the accumulated light of the first galaxies. And we did actually succeed in all of these objectives with the COBE satellite. This project was remarkably risky, considering when it was proposed and what it was like at the time. This was proposed in 1974. I organized a team six months out of graduate school to propose this mission, and when NASA decided to take us on as a serious study, they were taking a risk on us. But we did actually get associated with a truly wonderful engineering team at Goddard Space Flight Center and they produced this whole thing. It was an in-house project, which is not one of the more common ways that we do projects at NASA. But it was a wonderful thing for this project.



A map depicting the distribution of cosmic background radiation, as detected by the Cosmic Background Explorer (COBE) spacecraft. (NASA Image # 90-HC-640)

In 1974 people did not have computers on every desk. We did our first engineering drawings with pencils. And our calculators, our computers, were HP35s, and it was a miracle to have one. So people thought differently about risk because there was just too much you could never figure out or calculate. You did not have a finite-element model of everything you wanted. You just said, "Well, I think that'll probably work." And sometimes you were right and sometimes you weren't.

So then there was testing. This went through two metamorphoses. COBE was proposed first as payload for a Delta rocket. Then NASA went and put all of its eggs in one basket with a lot of kick from Congress and said, "We're killing all the expendable launch vehicles. We're going to send everything up on Shuttles." So this was redesigned to go on a Shuttle and it was a 10,000-pound spacecraft that had to go up from California. As far as I know, it was the only scientific payload that was to have the Shuttle launch from California.

Then the *Challenger* happened when we had more or less completed our design and were putting our spacecraft together. And it became pretty clear that there was not going to be a Shuttle launch from California ever again, and it wasn't just because the Shuttles were dangerous—there wasn't enough traffic for the purpose.

So we had to rebuild it all. We had also about a 30-month schedule we had to meet to rebuild everything. Fortunately, we did have the instruments that were more or less complete. And the business end did not really have to change much. But everything below that did have to change, and it was all new mechanical and thermal structures.

So our Deputy Project Manager took a risk. He started hunting around in the rest of the world for a foreign launch vehicle, and Headquarters informed him that he would lose some body parts if he kept on doing that, and that was a risk. Headquarters did, however, recognize that potentially this mission could be the first new science mission to go up after the *Challenger*. And so they said, "Well, if we could get you a Delta, could you fit?" So the answer was: "Yeah, just barely." And so the Delta was found. It had to be brought together from the spare parts left around in hangars elsewhere and pigeon droppings had eaten holes through the tanks in a few places. They were welded closed. So some of the stuff was a little bit of a risk.

But that was not the hard part. There were quite a few other kinds of risks in here. Of the business end, the scientific instruments, two of them were located inside a helium cryostat, and we had almost no experience with operating anything at very low temperatures. Certainly, our space engineering team did not know much about it. We all learned a lot going through this project.

> . . . MY FIRST THING IS, IF IT'S NOT TESTED, IT WILL FAIL, AND THAT YOU PROBABLY WON'T BE ABLE TO FIX IT EITHER.

Another really tough challenge that afflicted us seriously in the early days was that our budget was always limited. We didn't enjoy the virtue of being a top-priority project. So there were quite a lot of things that we did that were probably wrong, but we just knew we couldn't get the money to do the thing right.

However, that did change after the *Challenger*. And, so, the management approach changed. Charlie Pellerin came around and said, "If there's anybody on this project who knows any reason why this isn't right, tell us now." And he was pretty serious that we would have to tell him. He wanted to know the bad news, if there was any, because he needed to make sure this was going to turn out. So, I think this was an example that management attitude and our ability to raise funds to do the right thing were critically important to success.

Anyway, the whole story as best I could tell it is recorded in a book called *The Very First Light*. It's about ten years ago now, and it was written for a general audience. People told me afterwards they were out of breath from reading it because there were so many hazards that we faced and recovered from; and I think that's not unusual in the space business.

But it was worth it. We showed the spectrum of the universe is a perfect blackbody spectrum for a temperature of 2.725 plus or minus .001 Kelvin, which in its earlier incarnation brought us a standing ovation when we showed it to the American Astronomical Society. The question of whether the Big Bang theory was correct at all was still a somewhat open issue when this was reported. And to produce such a perfect measurement was tremendous cause for a celebration. And all the critics finally had to give up and agree that, well, maybe the Big Bang was really right. A map of the brightness of that background radiation over the entire sky was used to not only confirm the Big Bang story, but also to start in on the question of what's the rest of the universe like? The map and the details tell us basically that it's true—we're only 4 percent of the total universe, the matter that we know about. There's something like 20 percent more dark matter that still has attractive gravity. And we weren't quite sure then, but we were beginning to get onto it, that there's also a repulsion force that causes the acceleration of the universe. The universe is going faster and faster, and danged if I know what that's about! A lot of people have guesses, none of which we can confirm as yet. So this is a very open subject.

So these two results basically started up immense industries. There has already been a successor spacecraft for the measurement of the map and it's done far better. There's another one planned, and another one is hoped for after that. So we have made tremendous results out of this project, which seemed extremely risky technically.

Now, I want to go on to something that's perhaps easier in a sense, but much more difficult in another, the James Webb Space Telescope. This mission is the scientific successor to the Hubble Space Telescope, and it was conceived a long time ago, back in 1995, as the successor. And it's a scientific successor, but not a replacement. A lot of people are very concerned about what the future of Hubble is, and for anyone who cares, this is not a replacement.

This is not doing what Hubble does. This is looking farther away into the very distant universe and looking deeper into the places where stars and planets are being made, and it's much more challenging in a different way. To accomplish the objectives we need a much bigger telescope than Hubble. Well, how are you going to do that? Well, I'll show you. It also needs to be very, very cold because we need to see infrared light. The most distant universe is red-shifted, as it appears to us. The ultraviolet light that was emitted by those most distant things we want to see comes out in the infrared. And the visible light and other things come out in much longer infrared wavelengths. So we have to have a full telescope, and we are driven to a solution that happens in deep space. So we couldn't find any way around it. We sure knew that it would be great if we could service this mission as the Hubble had been serviced. We could not find a design that would allow that.

So we did negotiate a deal with the European and Canadian Space Agency and we did get the blessing of the National Academy of Sciences that this was the next big thing. It is a vision which strikes fear and trembling into the hearts of engineers, because the payload escapes from the Earth. It's going to go a million miles away from the Earth and when it gets partway out there it's going to deploy. And deployment in mechanical devices also terrified many engineers. We've had a lot of trouble with mechanical things and they're plenty right to be worried about it. It's got its solar arrays to deploy, then a solar baffle, a heat shield, then graphite fiber poles, a little bit stouter than fishing poles but not a whole lot. The shield pops open and becomes five layers. The five-layer shield is a much better thermal shield. Then a support tower is erected and the secondary mirror comes out and deploys on its linkages. The gold-coated primary mirror there is made out of beryllium hexagons, but it's coated with gold. And it deploys one wing of the hexagon, and now the other wing.

It's a million miles away. It's a million miles in the opposite direction from the Sun. There's a point called the Lagrange point L2 where it's a semi-stable orbit. And if you hovered around that spot, you could stay there with only a small nudge and move around the Sun with the Earth all year long.

So that's where we're going. This is the thing that's supposed to go there. And if you had asked us ten years ago if this was going to work, people would laugh at you and say, "Nah, you couldn't do anything like that." The company that's building this for us is Northrop Grumman. It's next to L.A. airport. And they tell us that they've actually deployed many, many things in space for other government agencies which they can't tell us about! But there is a reason why this technology was much more mature than astronomers ever imagined.

So, anyway, there's an awful lot of engineering risk in that thing. We had altogether twelve contracts to learn how to build the ultra-lightweight mirror that we need. The mirror is a chunk of beryllium, which is polished to the required accuracy. And we've proven that it will stay the right shape when it cools down. So this is a truly remarkable accomplishment. And, jeepers, it looks just like a mirror, doesn't it? But it took years and years of cooperative technology and competition.

Now, I want to show you the result as a formal tool that we use for analyzing risk. If we didn't have a formal tool I'm convinced we could never get there, because the way that we did risk analysis for the COBE project was: "Well, I think it'll work or I think it won't." Now we have a very formal process. We have a giant risk database. Our risk manager is here if you want to ask her more questions about it.

But we have engineers that fill out forms and we have weekly meetings, and we keep track of every single thing that we're worried about. And sometimes we retire it and sometimes we say, "Oh, it's getting worse," and we have to do something more vigorous about it. At least three of the top issues for us were questions about people—you know, can the agencies agree on something? So this is an example that's very typical, that some of the hardest problems are negotiations. And I just wanted to emphasize that we have a method for doing this, and never to forget what the problems are.

I wanted to share some of my observations of physical things with you. And this, I have to admit, started with my learning experiences in school. I had a thesis project which failed on its first flight, and I learned a lot from that failure. And I know how we got into that mind-set that said, "Well, let's fly it anyway." We were tired, and we didn't have any more money. However, this thing did not work for three different reasons and so I learned something.

So, my first thing is, if it's not tested, it will fail, and that you probably won't be able to fix it either. And sometimes if it is tested, it will fail anyway, but at least you'll have a chance to fix it. But it will cost you. If you don't have a spare part or a backup plan, it will definitely fail. And if you only test it a little bit to see if it will do what it's supposed to do, then it'll do something else. So I've come to a similar conclusion to what Steve Squyres was recommending: You need lots of hardware around to work with, because things are going to go wrong and you need to be able to test out your idea on one thing while you're fixing the other one. So you need to have a lot of smart people thinking a lot about really terrible things, things that could go wrong and might just go wrong, and not being too limited to thinking about the things that you only know you can fix. Things that have the highest consequence will often be things that you missed because, you know, "Oh, I can't fix that." So you need lots of external review and we do have lots of external review. And so that's the number one thing.

There's another issue, about individual people. I don't think that human beings as a group are particularly good at balancing lots of likelihood and consequence. I know a lot of people [who] have fallen off of things and hurt themselves badly, including one of our senior managers on the COBE project—after he retired, fortunately for the project. So we're not really good at this. We need a formal tool. And we have a formal tool, but if you don't use it, you will definitely be in trouble! That's a conclusion from this.

So I think our greatest risk is lack of imagination. A lot of imaginary things you just have to explore. Once you've decided where you're going to go with what you get from your imagination, then you have to imagine all the things that could go wrong. You have to rehearse all that. If you were a performer, as my wife is, then you rehearse before you go out on stage. And people who are successful in our business rehearse and rehearse and rehearse, too. But I know that, at least in my history, we have been very easily blinded by thinking about what we have to work with rather than is it actually required? Nature doesn't really care whether we have enough resources to think about this problem. Either we did it right, or we didn't. If you didn't build it right and you think of this fact, then you better tell people and get the resources. Otherwise, you might as well not have started.

NASA Image/Renee Bouchard

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From the Earth to the Moon

I'm just a Hollywood screenwriter, and when I look at the people on this panel, I think I'm the answer to: "What's wrong with this picture?" The other thing that comes to mind is my *Mission to Mars* credit. There's a thing in Hollywood where you fight hard to get credit on something, because you'll usually get some money when the DVD sells. And you have to weigh the value of that money versus being humiliated in front of people at NASA for having been involved in a movie as bad as *Mission to Mars*. So—I really don't know if it was worth it. But anyway . . .

In 1996 I got a call from my agent and she said that Tom Hanks was doing a history of the Apollo program for HBO and did I want to be involved, and I said, "Sign me up." I read the outlines that they had prepared and I read Andy Chaikin's book. The episode that jumped out at me for dramatic purposes was the episode that, at that point, was then called "The Fire." It was later re-titled, for good reason, "Apollo I." They said, "Sorry, that's already taken by another writer." And the next day, I got a call that the writer had dropped out, so I got a chance to write that episode. In a very personally selfish way, that changed my career. Up until that point, I'd been an action writer. I did *Speed* and *Broken Arrow* and

Graham Yost
Writer/Director

Graham Yost is a writer/director from Toronto, Canada. His work includes the television series *From the Earth to the Moon* (1998), *Mission to Mars* (2000), and the 1994 box office hit *Speed*, starring Keanu Reeves.

OPENING PHOTO:
Astronaut James A. Lovell, Jr., commander of the Apollo 13, testifying before members of the Senate Space Committee about the problems of the Apollo 13 mission.
(NASA Image # 70-H-515)

those were fun movies, but this was the first time I got to write real people and really interesting and real dramatic situations. And I remember the highest compliment that I got was, at one point, Frank Darabont was going to direct the episode—Frank Darabont has directed *The Shawshank Redemption* and *The Green Mile*. He said while he was reading it, he kept on flipping back to the title page and saying, "This is the bus guy?"

As a little Canadian boy, I watched the Moon program from Canada and just loved it, which is why I said I wanted to be on board—but it made me a true space geek. The term on *Earth to the Moon* was "you've become a helmet-sniffer," if anyone knows the term from sports. That's why I'm here. And we would follow around Dave Scott, our astronaut adviser, and I remember telling my wife, "I just keep looking at his feet," because those feet were on the Moon.

In the writing of this episode, "Apollo 1," I decided very early on that I wanted to focus on Frank Borman, who was part of the Apollo 1—it was actually, technically, called the Apollo 204 Review Board. We're going to show a clip from the episode. So this is Frank Borman. It's later on in the episode and it's Frank Borman, played by David Andrews, who's testifying in front of a Senate committee. And I made Walter Mondale the bad guy, but that's a whole other story.

[Dialogue from video clip is indented.]

> *Senator Mondale:* Colonel Borman, would you have entered the spacecraft on the morning of the accident if your turn had been called?
>
> *Frank Borman:* Yes, sir.
>
> *Senator Mondale:* Would you have had any hesitancy?
>
> *Frank Borman:* No, sir.
>
> *Senator Mondale:* Were there defects in workmanship?
>
> *Frank Borman:* There were.
>
> *Senator Mondale:* And did these defects go beyond workmanship?
>
> *Frank Borman:* Yes, sir, there were defects in design.
>
> *Senator Mondale:* If you had entered that spacecraft on that morning, would you have been motivated by a desire to take risks?
>
> *Frank Borman:* No, sir. Sometimes there are romantic, silk-scarf notions attributed to this business, but we're professionals. We will accept it, certainly, but not undue risks.
>
> *Senator Mondale:* Let me rephrase the question. Knowing what you know now, would you have entered that spacecraft?
>
> *Frank Borman:* No, sir.
>
> *Senator Mondale:* Colonel Borman, how did Commander Grissom and his crew feel about the readiness of the vehicle?
>
> *Frank Borman:* I talked to Ed White shortly before the accident.

He thought they were over most of their problems and were on their way . . .

Senator Mondale: Didn't Commander Grissom once hang a lemon on the simulator?

Frank Borman: You had to know Gus.

Senator Mondale: Did Commander Grissom hang a lemon on the simulator?

Frank Borman: Yes, sir.

Second Senator: [interrupts Mondale] Tell us about him, Colonel. Sorry, Senator, I just have a couple of quick questions. Would you yield for a minute or two?

Senator Mondale: Actually, Mr. Chairman, I—

Second Senator: Thanks. Colonel Borman, you just said, "You had to know Gus." And I think that that's been missing in here the past few days. I'd like the record to contain just a little about the men who perished in that fire. Colonel, could you do that for us?

Frank Borman: Gus Grissom was the first astronaut to be asked to fly three times. Mercury, Gemini, and Apollo. He loved being an astronaut, except for the publicity and display that comes with the job. There are no front windows on the house he built for Betty in Timber Cove because he didn't want people looking in. If that gives you the impression that Gus was a cranky SOB, well, he was, at times. But I would have trusted him with my life.

This photograph shows the crew in training for the ill-fated Apollo/Saturn 204 mission, more commonly known as Apollo 1. On 27 January 1967, a sudden fire broke out in the command module during a launchpad test. All three of the primary crew—astronauts Virgil "Gus" Ivan Grissom, Edward Higgins White II, and Roger Bruce Chaffee—perished.
(NASA Image # 66-HC-1834)

Ed White was a big man for an astronaut, a shade under six feet. As you well know, Ed was the first American to walk in space. There's a story going around that when he was on his spacewalk, he stayed out after he had been ordered in because he was having such a good time. Funny story, but it would have meant Ed White disobeyed an order. Not going to happen. Ed was a West Point man. Duty, honor, country were not just words to him. He was one of my closest friends.

Roger Chaffee, I didn't know that well. He was one of the new guys, very energetic, very excited. I heard a story about him, though. He was out on Long Island visiting the Grumman facility where they were building the descent stage of the lunar module. He saw a group of men standing in the corner. He found out these were the fellows that make the tools that make the machines. None of the big wigs that were escorted through there ever talked to these guys. But Roger went over and made them feel like they were the most important part of the program.

Second Senator: Colonel, this isn't a court of law, so I can ask you something that's completely hypothetical. If you could somehow reach beyond the wall of death and talk to Grissom, White, and Chaffee, what do you imagine they would say about the fire?

Frank Borman: I was—I was hoping that someone would ask that. I don't know what Roger or Ed would say, but I can let Gus speak for himself. Back in January, he talked to a group of reporters. They asked him about the dangers involved in going to the Moon.

[Additional indentation to set off reminiscence of Grissom speaking.]

> *Gus Grissom:* We're in a risky business, and we hope if anything happens to us, it will not delay the program. The conquest of space is worth the risk of life. Our God-given curiosity will force us to go there ourselves, because in the final analysis, only man can fully evaluate the Moon in terms understandable to other men.

Second Senator: Colonel, at the risk of being gruesome, we've heard about the fire from everyone who was there, everyone except the astronauts themselves, of course. Can you tell me what they went through? What it was like for them?

Frank Borman: I can only tell you what we know or, at least, what we think we know. When it happened, they were just waiting for the test to resume.

[Additional indentation to set off flashbacks to astronauts caught in Apollo I fire.]

> *Gus Grissom:* How are we going to get to the Moon if we can't talk between three buildings? I can't hear a thing you're saying. Jesus Christ, I said, how are we going to get to the Moon if we can't talk between two or three buildings?

Frank Borman: They didn't see the spark that caused the fire because it was behind the panel door, down below Gus's feet. Because of the oxygen, the spark was able to jump out into the netting under the seats. Gus probably saw it first because it was closest to him.

> *Astronaut:* Fire! We have fire!

Frank Borman: Procedure would have had Gus push down Ed's headrest so that Ed could have started turning the latches.

Astronaut: We have a bad fire! [pause] Hurry up!

Frank Borman: Now, it just took me a minute or more to tell you all that. In actuality, from the first mention of the fire to the rupture of the hull only 15 seconds went by.

Second Senator: Colonel, what caused the fire? I'm not talking about wires and oxygen. It seems that some people think that NASA pressured North American to meet unrealistic and arbitrary deadlines and that in turn North American allowed safety to be compromised.

Frank Borman: I won't deny that there's been pressure to meet deadlines but safety has never been intentionally compromised.

Second Senator: Then what caused the fire?

Frank Borman: A failure of imagination. We've always known there was the possibility of a fire in a spacecraft. But the fear was always that it would happen in space when you were 180 miles from terra firma and the nearest fire station. That was the worry. No one ever imagined that it would happen on the ground. If anyone had thought of it, the test would have been classified as hazardous. But it wasn't. We just didn't think of it. Now whose fault is that? Well, it's North American's fault. It's NASA's fault. It's the fault of every person who ever worked on Apollo. It's my fault. I didn't think the test was hazardous. No one did. I wish to God we had.

Second Senator: Now before we all go home, is there any statement you personally would like to make?

Frank Borman: I think I'm safe in speaking for all the astronauts when I say that we are confident in our management. We're confident in our training, in our engineering, and in ourselves. The real question is, are you confident in us?

Second Senator: What do you think we should do Colonel?

Frank Borman: I think you should stop this witch-hunt and let us go to the Moon. [Applause]

Second Senator: Senator Mondale, back to you.

Senator Mondale: Thank you, Mr. Chairman. I have nothing further.

Second Senator: Thank you, Colonel.

[End of video clip]

John Grunsfeld: I'm going to exercise my executive privilege here for just a minute, and I'll let Graham continue, but, Graham, this is why we invited you. I can't help watching that without getting a little tear in my eye. I've been up at NASA Headquarters for a little over a year. When I came to Headquarters after the loss of *Columbia* it was because of the pain that I felt for the crew and my friends and this kind of circumstance. When I started watching this video

I thought, welcome to Mr. O'Keefe's world. And Bill Readdy's world. And all of us here from NASA who had to suffer through the loss of *Columbia* and crew. This really does address the central issue that we're here to discuss, which is how do we decide, when do we decide to go on, given the loss of our friends, for something we all believe is crucially important personally, professionally, for the planet, and for our friends.

I know Mr. O'Keefe has to leave in just a little bit, but I'd like to take this opportunity just to thank you as, hopefully, folks thank James Webb for the perseverance, the energy. For those of you who [don't] know me, I am an intense workaholic. I can look to a few members in the audience who are shaking their heads in agreement and Mr. O'Keefe, you're the first person that I have been unable to keep up with. Thank you very much. Thank you very much for helping sponsor this risk symposium.

I think in a nutshell that things like that video clip show the key to communicating this risk to the public effectively. So, back to you.

THIS REALLY DOES ADDRESS THE CENTRAL ISSUE THAT WE'RE HERE TO DISCUSS, WHICH IS HOW DO WE DECIDE, WHEN DO WE DECIDE TO GO ON, GIVEN THE LOSS OF OUR FRIENDS, FOR SOMETHING WE ALL BELIEVE IS CRUCIALLY IMPORTANT PERSONALLY, PROFESSIONALLY, FOR THE PLANET, AND FOR OUR FRIENDS.

Graham Yost: Thank you very much. After working on *Earth to the Moon*, I was looked at in Hollywood as the guy who, if NASA ever had a problem, would write the thing about it. So I became the disaster guy. This was also incredibly tough. I wrote a screenplay in '99 on *Challenger*. That has never been produced. Partly because, I think—it was for 20th Century Fox—and they were looking for white hats and black hats, and what I found was human beings.

Then, I got to work for HBO on a thing on *Mir* and looked at Jerry Linenger's experiences up there and the fire that they had. Also Mike Foale and the docking incident. At any rate, though, *Earth to the Moon* was the focus for me in risk. We shot it mostly in Florida. We did the lunar surface stuff outside of L.A., but we shot the rest of it in Florida. Our joke at the time was, just like the Moon program, we're thousands of miles from home, we're spending way too much money, and it's taking too long. The difference was, and it's been mentioned about the robotic missions, there were risks to career, risks to family, but there really, ultimately, was no risking of life in doing a miniseries for HBO and hanging out with Tom Hanks. That's not a hard thing.

But when I think about risk as I've heard over the past couple of days, I'm reminded of George Carlin's famous line—judging risk is very subjective.

George Carlin's line about driving was, "Have you ever noticed, anyone driving slower than you is an idiot and anyone who's driving faster is a maniac?" In hearing some of the things, we feel like we can somehow judge our own risk level. We know what we can handle. The classic subjective thing is flying versus driving. We know statistically flying is lot safer, and, yet, somehow, we feel that if we're in charge, we can handle that risk. I remember when I was living in New York and some crime had happened to a stranger. That was the thing we were always concerned with, stranger on stranger crime. You would find out when it happened and where it happened and you'd say, "Oh, I never would have been there." So, it's not risky.

In terms of Apollo, as I said, one of the great honors of doing *Earth to the Moon* was meeting the astronauts and spending a lot of time with Dave Scott. I got to direct the episode about Apollo 9. So I spent a lot of time with him talking about that. I also worked with him getting the script ready for the episode covering the Apollo 15 mission. He told me that there was a big discussion about what the rover walk-back limit on it would be, how far the rover could go before, if it broke down, they would have to walk back to the LEM. The proposal was that they should have—I forget the term—it was like a double walk-back limit or something. Because, what if the rover failed and one of the Portable Life Support System (PLSS) backpacks failed, that they should be able to go back on one PLSS backpack. Dave said, "No. That's just going to hamper us too much. That's going to hamstring us. We need to go as far as the single walk-back limit." I said, "Well, what would have happened if you had a PLSS failure and a rover failure?" He said, "Well, we would have had a bad day." That was his perspective, and that was his choice.

Thinking about risk and NASA and space exploration, you have to realize that people like Shannon Lucid and people like [Harrison] Jack Schmitt and the other astronauts, they're perfectly capable of judging whether or not something is safe. Just like David Andrews, Borman is saying: We know what we're willing to take. The reality is that space exploration, unlike the *Magellan* voyages, has been a volunteer thing. There's been no torturing of astronauts and telling them that they have to go into space. Which again, may not be a bad idea. [Laughter] It's important not to rule anything out.

This does bring up the other project I worked on in which that was always one of the questions. Judy Resnik and Dick Scobee and Elison Onizuka knew what they were dealing with in spaceflight but did Christa McAuliffe really know? Did Greg Jarvis really know? The thing is, they were told. They were told as well as anyone can communicate to them. It's not about statistics. Dick Scobee told Christa McAuliffe the classic line, "When you launch the Shuttle, everyone is at least three miles away except for us. We're going to be sitting on top." For me, in researching *Challenger*—and again it's probably one of the reasons it didn't get produced—was that the problem with *Challenger* wasn't that NASA somehow got lax with risk. There are all these theories, by the way. I don't know if any of you have read these books, but that NASA was pressured to make the launch in order to meet up with Reagan's State of the Union address that night and all this stuff. The future of space was in Reagan's hands, that there was pressure, pressure, pressure. I think that's absurd, when you look into it, and that's what Dave Scott would call an "outside the culture" view of it. When you get inside, you realize it was just people doing the job they had and the best job they could. Everyone working on the program knew the astronauts or met them at some time. There was no laxity in NASA on risk.

To me, in looking at it, the problem was with public perception of risk. This has come up again and again over the past couple of days, but because I'm last I get to say it again anyway. What can the public tolerate? What are they expecting? I think that when *Challenger* happened, NASA was a victim of its own success. If you consider Apollo 13 was a close call. We've heard that term mentioned, but other than that, it was just a string of successes with manned missions. The expectation in the public rose. There was also media pressure—the media fed into that. There was a classic tape of Peter Jennings on the 26th of January—the night before *Challenger*—saying another on-time departure is too much of a challenge for *Challenger,* because there was a socket wrench that they couldn't work.

But, the truth be told, NASA at that time was part of the problem, because NASA had promised that the Shuttle was going to be a routine access to space. As anyone who I've talked to involved with spaceflight knows, there's no such thing. It's not routine. It's not—as Mike Foale said last night—it's not flying a big aircraft. It's something far more complicated and far more risky than that. During the Presidential Commission on *Challenger* a figure came up and I don't know the source of it so, if it's not true, forgive me, but it has been said that the Shuttle stood only a 1 in 100,000 chance of having a disaster. It was Richard Feynman, who was on the commission, who worked out the simple math that that means the Shuttle would launch once a day for three hundred years before something happened. That was an unreal expectation, an unreal offer to the public, that it's going to be that good, that sure.

The thing is that we have public accountability. We have a transparent program. There are problems with that, but I still think the good outweighs the bad. In researching the NASA stuff, we also, at one point for *Earth to the Moon*, we were going to do a special two-hour episode about the Soviet program. It just became too expensive. One of the things that we found out is that there were horrific accidents. The testing of an N1 with over 1,000 people killed in one explosion. No one ever heard about it. No one in North America ever heard about it. No one in Russia heard about it.

In fact, I would say that culture of secrecy is something that, as Mike Foale said last night talking about the docking crash on *Mir*, contributed to that: The idea that we don't have to share everything. We don't have to tell you everything. It's all okay.

My closing thoughts have to do with the question of humans versus robots. A lot of people have said it's kind of an absurd question. They have to go hand in hand. To me, humans versus robots is, frankly, not about risk. Ultimately, it's about money. My feeling in having written about space exploration is that the notion of risk is almost secondary to whether or not we move forward into space. I think the public will bear whatever the risk is because they know that the people involved will bear it. Because the astronauts sign up, because it is voluntary. The question becomes, is the public going to get behind it? The public is important because they're paying for it.

Even though I'm Canadian, I pay American tax dollars. So, it becomes a public concern. If something happened back in the 1960s to Lockheed or Grumman or a North American test, well, that was private enterprise. That's okay. That's their deal. That's their pilot. But when it's our pilots, when it's our astronauts, then it becomes something that people have to get behind.

Dave Scott told me that Neil Armstrong once gave a presentation saying—and this is sort of a gloomy note to end on—but going to the Moon was really the convergence of several important things. The technology was available, the money, and there was the public will. And I think the big question is going to be

MY FEELING IN HAVING WRITTEN ABOUT SPACE EXPLORATION IS THAT THE NOTION OF RISK IS ALMOST SECONDARY TO WHETHER OR NOT WE MOVE FORWARD INTO SPACE. I THINK THE PUBLIC WILL BEAR WHATEVER THE RISK IS BECAUSE THEY KNOW THAT THE PEOPLE INVOLVED WILL BEAR IT.

to get the public will to go back to the Moon and on to Mars. And I don't know if it's just a matter of communicating it. I think it is also a matter of, somehow, in the zeitgeist, the public has to get behind it. Beating the Soviets was worth it. People just signed up and said, it's worth it. I think that if we found out that a Mars base was crucial to protecting us from an asteroid storm or alien invasion, we would be there in 10 years.

So what I believe that NASA has to do is to embark on a massive campaign of disinformation and lies. [Loud laughter.] And I pledge to do whatever I can. ■

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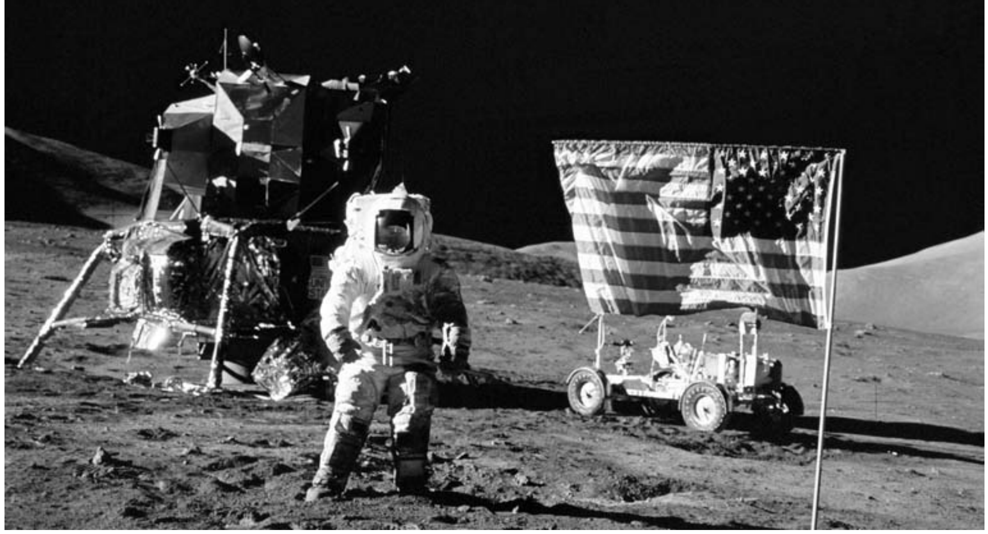

Discussion

JOHN GRUNSFELD: Welcome back to "Risk and Exploration." Our panelists are eager and ready to answer and discuss all of your questions and concerns. I imagine that the audience has plenty to offer, so I think what we will do is start. If you do ask a question or make a comment, please make sure and stand up, give your name and affiliation, and wait just a moment for them to cue up your microphone.

UNIDENTIFIED SPEAKER: I don't quite know how to phrase my question. It's been bothering me for the last day and a half. It was illustrated very nicely in the film clip we saw. There's an old set of characteristics of projects that has been going around for years, the last two of which involved praise and honor for the nonparticipants, and the last one is search for the guilty. The search for the guilty was illustrated there with the cross-examination of the astronaut for causing a failure. I guess I have been bothered for years by the fact that there always seems to be a need for institutional witch hunting. Somebody has to be guilty. This has got to be an inhibiting factor for managers and the people who have to make the tough decisions. I wonder how people feel about that. Is it really an inhibiting factor, or do you not think about it?

JOHN GRUNSFELD: That's a great question. I guess you missed the *Barcelona Times* in 1522 when Magellan didn't return, and they started the witch-hunt there. It's an interplay between Congress, the media, and the transparency that Graham discussed. We want to have a transparent space administration. That's part of our process.

JIM GARVIN: Sometimes the side effect of that mind-set is stimulated reexamination of programs. It has been said, and I've heard it said here, that we have programs in NASA. The one I speak for here, the Mars exploration program, continuously reinvents itself, precipitated by different types of catalysts. Sometimes they are the big setbacks. We did that after Mars Observer—the big witch-hunt of the early '90s. We did it after, as Steve said, the Climate Orbiter/Polar Lander issue, and we built a better program. So, that transparency and these effects you rarely see sometimes have positive consequences. How to live in the risk world without them in a highly visible public program is the debate we should all have. In the case of Mars, I can say that the level of incisiveness and the view that we took to do the rover, to

OPENING PHOTO:
Astronaut Harrison H. "Jack" Schmitt, lunar module pilot, stands near the United States flag on the lunar surface during NASA's final lunar landing mission in the Apollo series (1972). (NASA Image # AS17-134-20382)

do Mars Odyssey, which is still operating, and that we are applying to the Mars Reconnaissance Orbiter has been, perhaps, catalyzed by this mind-set.

GRAHAM YOST: In researching *From Earth to the Moon*, the feeling after the fire in Apollo I and the death of the crew was one of recommitment. The whole program just came together stronger and better than before out of that. I remember researching *Challenger*. There certainly was a witch-hunt, and Larry Malloy at Marshall became the fall guy. He once said that he understood that, as the middle manager in a corporation, his neck would be the one to go and his head would be the one to roll. I would say, and everyone here is in NASA after *Challenger* and you will see NASA after *Columbia* as well, that there is sort of a recommitment. I think, from the outside point of view, it's sort of a program that gets stronger.

STEVE SQUYRES: I think it serves no useful purpose nor is it in any way appropriate to have a search for the guilty parties. It just doesn't do anybody any good and should be avoided. At the same time, you cannot let your desire to avoid that scare you off from a ruthlessly self-critical evaluation of what went wrong. T. K. Mattingly last night said that every great success is preceded by failure. Certainly that was the case in the case of our mission, and I can tell you right now that the MER [Mars Exploration Rover] mission, as one simple example, would not have succeeded had it not been for the ruthlessly critical self-evaluation that NASA undertook of its Mars program, as Gene said, after the loss of MPL [Mars Polar Lander] and MCO [Mars Climate Orbiter]. I think the CAIB, the Columbia Accident Investigation Board, that Scott Hubbard was a part of, was a very necessary process. It was ruthlessly critical of the Agency in ways that were necessary and ways that will save lives in the future. We shouldn't have a witch-hunt, but you can't let it scare you off from doing a job you have to do when something goes wrong.

UNIDENTIFIED SPEAKER: I would like to add that I do picture myself sitting in Frank Borman's chair down here answering the questions. Now, you've said it was a good idea. You just gave up because you couldn't get the resources? Well, what kind of man are you, you know? It gives a person a little more courage to go tell the uncomfortable truth that you might have to tell sometimes.

UNIDENTIFIED SPEAKER: I think one of the questions that comes up as far as testing is the James Webb Space Telescope. The James Webb Space Telescope is a big telescope. That's why it has all that deployment, and it is still too small to do certain types of work that we know we would want to do at the end of the next decade: look for earth-type planets around nearby stars. I find that a compelling goal, and we need a bigger telescope. It will almost certainly be too big to test on planet Earth, and that gets back into the humans and robotic partnership. At what point are our goals important enough, our objectives well known, that the scale is such that we cannot test it on planet Earth? In the integrated test such that we might want to employ robots and/or humans as we do in the Hubble Space Telescope to check it out, how do you make that call? I know that this is something you've thought about, John.

UNIDENTIFIED SPEAKER: I would think that we have to do everything that we can with robots because they are probably quicker in most areas, and there will be some things they cannot do alone. When it comes to our dreams of big telescopes to find planets around other stars, I think we have to be really diligent in searching for ways to test them on the ground also. We just shouldn't give up on testing them on the ground, because I despair of convincing Congress that they have to fund us when we can't test it before we fly it. So, I think we have to be very, very imaginative about finding ways to test on the ground. We then still have to figure out that it's maybe not going to work.

There are some things we cannot adjust in the final stage and we cannot confirm on the ground. We have in mind flying constellations of telescopes that collect light from several different places and funnel it through a single combiner in the middle in an interferometer configuration, and with this method, you can build up the image sharpness that you would have from a telescope that is hundreds of meters, maybe kilometers or hundreds of kilometers across. You might want to do that to find out about those planets around other stars, but we just have no hope of testing that on the ground. Still, we must prove that it's going to work when you get there, so what are you going to use? Imagination? I couldn't tell you the answer today.

JIM GARVIN: We actually did experiments on the Moon with Apollo that you couldn't have tested on the Earth. The human beings, the crew set up some of the impressive arrays that we used to study the interior of the Moon and then experienced the collision of leftover space vehicles to generate a pulse; [that] was a novel, imaginative experiment that we did. I think there's an example of that. But there was something that we call Robotic Sample Return to bring back pieces of Mars to Earth. Some of us call it "Apollo without the astronauts" because of the complexity. The reason for that mission is because there are some things we think can only be done, at least until we reach projected technology state, with people in the loop. We either move a lot of people to Mars, and some of us would like to go, or we bring stuff back from Mars so the people here can work on it. Because of the testing limitations, you're there.

UNIDENTIFIED SPEAKER: One important point that I think is just good to get on tape is that there is no such thing as pure robotic exploration. The stuff comes back to the people who want to understand the science, so people are always involved. It's just a question of *where* are the people in proximity to the context. That's the evidence.

UNIDENTIFIED SPEAKER: Thank you, David Roberts. Problem for Jim Garvin and Steve Squyres and the panel. Besides Mars and Europa, what would be the likely planets or satellites for the next landers? Why? If possible, when?

UNIDENTIFIED SPEAKER: First, you left out the Moon. Going back to the Moon, it's a planet in its own right. While we visited tremendously with the humans, getting back there is a scientific and human operation proving ground. Mars is central to our vision, our implementation plan. So the Moon is a place. In fact, contrary to common belief, although not contrary to the science community, the Moon offers an interesting context for astrobiology. There's the question of early planetary crusts in which there may be aspects of our own history in the origins of life from which you gain context. Other than that, I would submit that it's a reconnaissance that will help answer that question. You named Europa. In January [2005], we will have the descent of the Huygens probe as part of the mission to Titan, unquestionably one of the most interesting objects in our solar system, certainly from the standpoint of planetary atmospheres and environments. Landing on that surface and sustaining landed experiments beyond the scope of Huygens is a wonderful step. We have a mission called Dawn that will visit two of the main belt asteroids, which are really planetary objects in their own right, Vesta and Ceres in this case, and landing on them, by virtue of what we find from the first nonlanded experiments that we'll be doing, I think is important. But I don't want to leave out Venus. Twelve impressive landings by our Soviet colleagues have left many questions that are so fundamental to understanding how big, rocky planets work, and their atmospheres, that we have no clue about. And, yet, that poses a risk challenge to sustain operations there robotically. I don't know whether the crews want to go yet, John, a little bit hard to get back in the gravity wall. There are a lot of places where landed experiments as a forerunner to sample returns and, ultimately, human landings, in my view, are important parts of our strategy.

STEVE SQUYRES: I think you answered it well. Actually, I'm glad you mentioned Venus because, you know, we have Venus, Earth, and Mars, and it brings us back to comments that Jean-Michel Cousteau and Sylvia Earle made this morning, which are, we like this planet, this is a nice planet we live on. And we also know we don't want to end up like Venus or Mars, and we don't understand any of them, including the Earth, all that well.

DAVID HALPERN: I'm happy somebody just mentioned Venus and Mars and the Earth. The point that was being made in the morning is not so much we don't want to end up like Venus with the hot house or the greenhouse gas—that's a separate issue. The simplest fact is that we know the topography—the ups and downs and the curves of Venus and Mars—to a much, much greater extent than we know the bottom of the ocean. That was one of the points that we were trying to make in the morning.

When it comes to exploration, if you want to explore, like Lewis and Clark, a continental area, what do you do? You first go there and you see what the height is and what the elevation is and where the streams are and where the gullies are. But we don't know that in the ocean. And the point that was being made—and then I think there was another comment made this afternoon—about 96 percent of the universe we don't know. Well, we don't even know 95 percent of the ocean. So, I just want to reiterate the point from this morning.

JOE FULLER: Joe Fuller, Futron Corporation. Right now, we're spending a lot of time, energy, resources, imaginations to reduce the risk associated with return to flight. And even though I'm sure everybody's going to do everything they can, there will still be risks. And if we think the unthinkable, what if there's another accident, you know, on the very next mission? It would have a devastating consequence. How do we get ahead of the curve in mitigating the risk of, you know, such a situation? I guess I'll refer to Graham Yost—he got very close to it in talking about, you know, dealing with the public.

GRAHAM YOST: Again, I think it comes back to the victim of success. The manned spaceflight in America has not been like test flight in America, where they had accidents all the time back in the '50s and people just kind of got used to that. God forbid, you know, that manned spaceflight had been like that. But it's hard to say what the public appetite is. Someone was asking me at the break about that, and I do maintain that the public is in many ways more concerned—I believe and I may be totally wrong in this—they're more concerned about the cost of things, because it's a pocketbook issue, than they are about the human risk. They're concerned about the human risk, but I think that they do feel that everyone is doing absolutely everything they can to make sure these people get back safely. I think that's just the tradition of the American spaceflight. And, so, I don't know what would happen to the Shuttle program. And, God forbid, you know, it took a long time, relatively, between *Challenger* and *Columbia*. That was a lot of flights, and it doesn't excuse it or make it okay, it's such an incredibly complicated machine—you all know. And the public doesn't know. But I think that the public accepts just the basic notion that it's risky.

JOHN GRUNSFELD: I don't know how Shannon feels, but I know for myself I'm more amazed each time we launch a Shuttle when you think of the tens of thousands of pieces, you know, that are checked out in the few seconds just prior to launch that all have to pass those checks before we actually leave. And the tens of thousands of people that all have to do their job just right before that Shuttle will leave the ground. It's always amazing to me that we do leave. I'm always a little surprised, when I'm in the vehicle, that we actually leave. I sort of prepare myself for that, you know, late countdown shutdown for some parameter out of limits, which many of us have experienced.

At the same time, Shannon, how do you compartmentalize? I know I do that. When I'm in the Shuttle thinking about the mission, I put the risk part of it, the scary part, in a little compartment, and it never really occurs to me when we're sitting out on the launch pad on four-and-a-half million pounds of explosives.

SHANNON LUCID: Well, you've made the decision that's what you're going to do and you've worked with the people that are doing everything. You've worked with the flight control team, you've worked with the Cape people, you know. And you know that they're doing the very best that they can. You know that they're only human; you know that mistakes can be made. And you've made your decision and that's what you're going to do. You don't sit there and analyze it and say, "What if?" at that time.

JOHN GRUNSFELD: That's right. In specific, we talk about the team aspects. And, as risk takers, regardless of whether it's earth, sea, or the stars, when you get into the vehicle or into the environment, ultimately, you have to trust those people who are making the decisions, and management, that they've done everything that they can. And often we talk about "as low as reasonably achievable" as a method of risk mitigation. For return to flight after *Columbia,* we have a very extensive guide, and the Space Operations Directorate has a very detailed return-to-flight plan. So, I think we're doing everything we can.

DAVID LONGNECKER: Hi, David Longnecker from the University of Pennsylvania. And my question is probably addressed to you, John. And that is, following up on what we just heard about mitigating risk, one risk we haven't really talked about so far—at least [to] any significant degree here—is the risk associated with a very large organization with multiple components, each doing their job to an optimal level, but, yet, creating a series of stovepipes that are not linked together across the organization. I'd be curious to know what NASA's doing to deal with that sort of linkage of risk across a huge organization.

JOHN GRUNSFELD: David, that's a great question. Thank you for asking that, and I think you saw on August 1st that NASA engaged in a rather large-scale transformation of its organization. The study of organizational risk in high-risk endeavors is a very mature study, but not very well understood. And you talked about stovepipes. The function of the transformation was to get NASA aligned behind a central goal. And you've heard that a lot. You have to have a clear goal. Everybody has to understand that goal, and everybody has to work together for that goal. In the Columbia Accident Investigation Board report, they talked about integration functions. And, so, one of the things that we've done is to strengthen, through consolidation and through this transformation, our ability to integrate. We have a Science Missions Directorate that now contains all of our science and has close ties with exploration systems, space operations, aeronautics; and we have an associate deputy administrator for integration who is the corporate conscience. And we develop our processes and policies to make sure that we have close integration between all these endeavors, whether it's the expendable launch vehicles in the science arena or human spaceflight and the exploration development. And part of that—and, I think, a key part of that—is so that we can incorporate lessons learned across the Agency into programs where those lessons may apply.

So, you know, that's not a full answer to your question, because it's only been a couple of months, but we're on the road towards trying to get that kind of integration and breaking down the stovepipes.

MITCH BARNEY: Mitch Barney, Goddard Space Flight Center. Ever since I was a college student, I've done my explorations in a bunny suit and clean-room booties.

I'm in the engineering side, developing new instrument-measurement techniques and technologies where failure is an option and the challenge is the risk—that's what brings you back day to day. Recently, the NASA environment for us has become a more competitive environment. We're competing and collaborating both internally and externally with private industry and with academia. And I wonder what the panel's response [is] to a question about the impact of a competitive environment on the risk that NASA's taking now. Dr. Mather and Dr. Garvin, you both mentioned the competitive aspects. So I wonder what you thought about competition and what it does—what's the impact on risk.

JOHN GRUNSFELD: I'd like to start this, if I could, with Steve Squyres. I came to NASA as a principal investigator in science programs and considered that process to be like swimming with sharks. Yeah, Steve?

STEVE SQUYRES: It is. I think that the competitive process that we go through—if exercised appropriately, if the selection process is done in an appropriate fashion—is one of the best risk mitigators that we have. My team, in various, different permutations and combinations, wrote three unsuccessful proposals—each of them, at the time, the best we could do, each of them with serious flaws—to agencies. We sent in the proposals. It was highly competitive. We lost. It was painful. We went back and we sharpened our pencils and we did a better job. And each proposal got better and better and, finally, on the fourth try, we managed to convince the Agency that something like MER was a good thing to do. I think that competitive process and the intensity of it—the pain and humiliation of losing a competition like that—drove us, and it drove us very hard to get better; and not just to write better proposals, but build safer, better, more-likely-to-succeed hardware.

And so, it's very important to have that competition. And I think the more broadly the net is cast—opening up the competition to industry, to universities large and small, across the Agency—to try to level the playing field so that everybody's competing on roughly equivalent terms, is a very, very valuable thing. And I dislike the competitive process intensely, but it's part of what has led to success of many programs doing that.

UNIDENTIFIED SPEAKER: I think the key for us at NASA is to make sure we provide you the tools and the ability to be able to compete head-to-head.

UNIDENTIFIED SPEAKER: If I may as well. I've seen the good and the bad of the competitive process for, in particular, science-driven experiments. And we haven't always gotten it right. I mean, Steve tells a good story, but we just spent the last couple of years going through that competitive process for 25 wonderful contests for missions to go to Mars, robotic missions, at this stage. And I think we've actually achieved a risk-based lesson learned from honing of that process. And I first saw that process as a loser, often, in the '90s, proposing instruments, but I later saw it from the standpoint of implementation, and I saw elegant things we want to do in space—both at Earth and on planets—get through the process with great imagination and excitement, and then fail to sustain the cost envelope, the research envelope.

And I saw the community get smarter, that is, the integrated aerospace, university, NASA center, you know, community. And in this last Mars scout go-round—my one knothole in this—we had dozens of brilliant missions to Mars. And in the end, the final four—I'm not a basketball player—emerged after withering reviews by hundreds of individuals in which we spent more time worrying about being attentive to understanding risk. In fact, the most withering review is the risk of implementation review we do. And I think, you know, to some extent, it's the setbacks that have honed that. So that I'm much more confident from all these analyses that we can do these things. Now, the question is, I think, how do we maintain continuous improvement of that process when we reach a certain level of performance—success from MER, success from COBE?

JOHN GRUNSFELD: I'm thinking that there are a lot of rules of the game that govern how it all plays out and that at NASA Headquarters, when we set up the rules of engagement, we basically determine the outcome—in a way that we may not anticipate—of how organizations grow or die. And the ability of organizations to grow or die as a response to the competitive process is part of capitalism, and it's part of the sort of basic religion of America, practically. But it does have some unintended consequences. Creative destruction is sort of [a] motto that people carry, and a lot of us may lose. So, well, that's just part of the deal. And I think that we need those competitive forces and, certainly, I've had a lot of losing proposals as well, so they know that and they deserve to lose, but maybe next time.

STEVE SQUYRES: There's one other aspect that we've mostly been doing with the science side, because we're a science-heavy panel, but Jim brought up the metrics by which you decide who wins the proposal. In the science case, we want projects that are viable, scientifically top-notch, and so on. One of the duties of the commander on a Space Shuttle flight—and I presume it was true of a Saturn V flight as well—is to remind the new fliers of the group that they're launching on the lowest bidder's successful project. So sometimes those measures of effectiveness may be at odds with low risk.

JOHN GRUNSFELD: It must be getting late. Well, Jim, let me pick on you for a minute and ask you something. You've flown a Shuttle experiment, and I've thought about this. My Ph.D. thesis was on a Space Shuttle. It was on the Space Shuttle *Challenger*, the flight before the fateful one, and I didn't think about the risk element to the crew at all. When you flew your laser experiment, did you think at all about the risk the crew was taking to get science for you and your colleagues?

JIM GARVIN: Well, in fact, John, we did, and for two reasons: One was the risk that we were afraid we were imposing on them. We had 45 millijoules, the number in laser metrics, a non-eye-safe, infrared laser transmitter. The light could have blinded the crew looking out the back window. And so we developed flight rules and procedures with the crew so that they would be sleeping, often, when we operated. For two reasons: We didn't want them moving around, because we were trying to measure little things on there, and, second, we didn't want that risk. But I remember vividly the launch of STS-72, which was in January of '96, and the biggest snowstorm in a decade in Washington[, DC].

And I remember thinking that the crew were launching, you know, not really thinking about the weather or getting to the payload operation control center at Goddard where they were running the experiment, which was causing me great stress, but I thought, they were riding these seven million pounds of thrust to carry our team's hundred kilos of stuff to try out an idea. And I thought how lucky we were. Because we had all the infrastructure that got them there into orbit successfully—in this case, it was a recovery mission for the Japanese—but also, to let us have this window on the world with this flight. We went with checked and set parameters, so I thought, if our straw is the one that breaks the back for the crew and, also for the mission and the Shuttle, that would be, you know, a tremendous setback.

We were scheduled to have an experiment like this on the first Shuttle launch for science out of Vandenberg. So, we were to go into polar orbit with the Shuttle to do experiments looking over the polar ice, being a big thing we wanted to measure. But, at any rate, it took us nine years to get back to our experiment on *Endeavour* when we flew. I just think those are the challenges of human spaceflight.

UNIDENTIFIED SPEAKER: I know, from the risk-taker's side, that the decision to go is very easy when it's making great science or great exploration. That makes it a much easier discussion to think about the risks versus the rewards. There are folks I've flown with out here in the audience and we've done tremendous science.

JOHN GRUNSFELD: Any more? Going once, twice. Very good. Well, I want to thank all of the speakers. Let's give them all a great big hand. I also want to take the time, once again, to thank the Naval Postgraduate School. It's been a tremendous venue for us and a great environment to have these discussions today for "Sea and Stars." Also for Ames, which has helped facilitate this. Don't forget, tonight is dinner and a movie. We'll be watching the *Endurance*. And for those out in the listening world, thanks for watching NASA TV. ■

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