The Vision for Space Exploration

There is no historic analogue, I think, to a gathering like this. Certainly, no records exist of people living in Lisbon 500 years ago attending a candlelight symposium featuring Amerigo Vespucci or Vasco da Gama or Ferdinand Magellan. So, this is an opportunity given by modern technology and the ease of transportation to pull together this really extraordinary group of folks who've experienced the full extent and breadth of exploration and the risks attendant thereto. Such a gathering was important for the purpose of parsing this larger question of risk and return on the exploration ventures we are about. I am particularly grateful to John Grunsfeld, who has really provided the intellectual horsepower behind this kind of effort to think about these questions in a structured way, and to Keith Cowing, two very disparate kinds of folks, but folks who share the passion and desire for exploration and an understanding of the attendant risk to it. So, to Keith and to John, I am most grateful for that extraordinary nudge that you all provided in pulling this together and providing the structure of the meeting.

We are gathered here, appropriately, in a place like Monterey, at the edge of a great ocean, to discuss exploration in all of it facets of extreme environments here on Earth and in space. Indeed, this historic location is steeped in a history of exploration. The ventures of

Sean O'Keefe
NASA Administrator, 2001–05

Sean O'Keefe was appointed by President George W. Bush to serve as NASA's 10th administrator. He served from 21 December 2001 to 19 February 2005. During his term, O'Keefe actively supported NASA's many missions to advance exploration and discovery in aeronautics and space technologies.

O'Keefe joined the Bush Administration on inauguration day and first served as the Deputy Director of the Office of Management and Budget until December 2001. Prior to joining the Bush Administration, O'Keefe was the Louis A. Bantle Professor of Business and Government Policy, an endowed chair at the Syracuse University Maxwell School of Citizenship and Public Affairs. Appointed as the Secretary of the Navy in July 1992 by President George Bush, O'Keefe previously served as Comptroller and Chief Financial Officer of the Department of Defense from 1989. Before joining then Defense Secretary Dick Cheney's Pentagon management team in these capacities, he served on the United States Senate Committee on Appropriations staff for eight years, and was Staff Director of the Defense Appropriations Subcommittee. His public service began in 1978 upon selection as a Presidential Management Intern.

OPENING PHOTO:
An artist's concept 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)

so many people to explore and to establish the site of civilization that we see in this marvelous area here around Monterey is testimonial to that. What we enjoy each day in this community, and understand about exploration and its benefits, are here and evident each day. Certainly this evening we will have an opportunity to see that more specifically at the aquarium.

I want to provoke some thought and reflection about a central question which we're discussing here in these two and a half days. Why do we take such risks to explore? As humans, what is it about us that really wants to understand that which is on the other side of the horizon, that which is on the other side of the ridge? In doing so, there are periods of our human history in which the acceptance of those risks have resulted in great gains and, in other cases a mere footnote, because it ended in a way that was less than fulfilling. In each case, there was always a contribution to that human desire to want to know and understand. How we assess those risks and deal with the challenges of exploration is the central question we are about in this two and a half days, and I am most grateful to all of you for accepting the invitation to participate in this kind of debate and discussion of how we may structure this question, not only in a public but also in a specific way. I am certain we will have a lively discussion of where you draw the line between the benefits of exploration and the inherent risks, especially as technology changes, and as we learn more about the environments in which we explore.

Now, this is in part about NASA participation, to be sure, but it is mostly about those of us from NASA having the opportunity to learn from so many others who are engaged in the broader exploration agenda of the central questions we pose.

I am most grateful to see the Apollo, Shuttle, and Space Station veterans who have gathered here with us to share their thoughts. Indeed, I think it will be historic in and of itself to learn so much from them. All of them have dared to sit in a spaceship at one point (and in several cases, like Jerry Ross, seven different times), to sit on the top of the spaceship with millions of pounds of explosive fuel, prepared to put their lives on the line in order to advance that cause of exploration and discovery. Now I asked Jerry, why you do this, and he said, "Well, because it's an opportunity to do so," and he would easily sign up for an eighth flight this afternoon, I'm sure. As a matter of fact, I don't think he would wait until noon to sign up for an opportunity.

To some, it may seem that NASA has made space travel routine. Let there be no mistake: I think we all fully appreciate and understand that space flight and exploration is still a very risky proposition. Despite our efforts to eliminate that risk, there will always be an attendant risk to such a venture. And, as a result, here in attendance are NASA scientists, engineers, and managers whose job it is to have constant vigilance about that risk. And in that regard, I view myself as included in that requirement for constant diligence to assure that risk is mitigated as much as we can.

From the discussions that will take place here, I hope we will gain a greater appreciation of our responsibility as a public organization to take on bold and risky ventures, and to learn from those who have accepted private ventures and other approaches to how we explore risk. We want to know how to frame that discussion and debate, and evaluate that risk in a different way.

But, again, it is also a requirement that we do that in a diligent manner that minimizes and mitigates, to the maximum extent we can, what that risk may be, that we understand what risk is as much as possible and, in some cases, accept it relative to the returns we think are feasible. That's the price of admission of what we do each and every time we're engaged in any exploration venture, be it of human spaceflight or robotic probes. It is always measured in the public domain

"WHY DO WE TAKE SUCH RISKS TO EXPLORE? AS HUMANS, WHAT IS IT ABOUT US THAT REALLY WANTS TO UNDERSTAND THAT WHICH IS ON THE OTHER SIDE OF THE HORIZON, THAT WHICH IS ON THE OTHER SIDE OF THE RIDGE?"

and in the public eye relative to what our expectations are to that return. Indeed, NASA is an agency that has been defined over the course of its 46 years by great, great triumph and unbelievably deep tragedy, and we've learned from both ends of that spectrum. It's a consistent set of themes. It is, indeed, the singular aspect of what has described this agency throughout the course of its four decades.

We have purposely expanded the list of invitees, and we are very grateful to the folks who have accepted to be a part of this. We want to gain an added perspective from the people engaged in exploration of the Earth's most extreme environments, and learn what they can bring to the question of why we explore in the face of danger. What is it about that act of exploration that makes it so appealing? And so important? And so much of an acceptance of human desire to want to understand and know that which we don't?

Within the NASA family, we have great respect for all who put their lives on the line: Not just to seek thrills, but, rather, to gain knowledge, wisdom, and experience that will benefit all humanity. All of those assembled here have a unique and exciting story to tell about what drives us to explore, whether engaged in it directly or specifically involved in supporting its effort, all with the same objective.

All of those stories, I have no doubt, we'll hear at this meeting. Also, we'll learn from the experiences of how folks work to minimize and mitigate the risk, and learn where the fine line is between responsible and imprudent risk. Where is the differentiating line that marks that? Even when we've applied a careful calculus to these kinds of circumstances, in many cases and in many circumstances, the events of nature will provide a set of risks that must be responded to, and challenges independent of whatever control we might have over it.

Our colleagues at the Kennedy Space Center, after their second hurricane in the span of a few weeks, are dealing with just that set of challenges, of risks that they are working through. And because of their extraordinary diligence, having survived two unbelievable events of what are natural disasters in their own right, nonetheless, have survived those experiences with all the Shuttle orbiters intact, all the space station hardware in great condition, and no loss of life, no injuries. It's an extraordinary testimonial to the amazing diligence of Jim Kennedy, the director of the Kennedy Space Center, and what the Kennedy team has done to ride out this set of natural disasters.

I was down at the Kennedy Space Center with Bill Readdy a week ago, and the poetic kind of discrimination with which nature provides us a set of challenges on risk were evident to us. I got an opportunity to see the Vertical Assembly Building, which is the dominant structure on the skyline of the Kennedy Space Center that all recognize, and you could literally tell which way the wind was blowing when Hurricane Frances blew in. Three of the four sides of the Vehicle Assembly Building were in relatively good shape. On one side of it, though, better than a thousand panels were blown off. Several of those panels have also departed as a result of the latest hurricane that just came through. As a consequence of striking some of the buildings in the area, ripping off big chunks of roof, all manner of consequence and destruction that occurred as a result of that, all of which was mitigated in some way, shape, or form. And yet, the irony is that right next to the Thermal Protection Building, where a portion of the roof blew off next to the Vehicle Assembly Building, there was a pressure-treated lumber gazebo without a scratch.

Nature discriminates very profoundly, and why it does, we don't understand. It certainly is a case that reminds all of us, even in such a simple example as that one, that despite our best efforts, there are unknowns that will always rise up in any of these circumstances, in any case of exploration, for which the only defense we have is diligence and the hope that we have mitigated against it as well as we can.

We're living in an era of great potential, one in which the exploration of the solar system and of the Earth's most extreme environments will boost the opportunities we have to become a smarter, safer, healthier, and more intelligent world. Certainly, we're more informed about the neighborhood we live in, a neighborhood defined as this little, bitty solar system around this little, puny star in a gigantic galaxy that is part of a massive universe. We are just on the cusp of understanding what our role is in that broader case, and it's only been in the last 40 years that we have come to understand it in ways that are really quite profound. I'm confident that if we do this right, we'll be amazed by the rapid pace of progress our future exploration activities will bring about.

But we also know from history about the consequences of forsaking exploration. When we evaluate and determine as individuals, or collections of people and nations, to forsake those exploration opportunities, it has consequences. In the 15th century, China had the opportunity to be the world's foremost maritime power and, indeed, possessed that capability. The Chinese ruling class, nonetheless, decided that the sponsorship of the fleet was an indulgence. History, in the course of the several centuries thereafter for that culture, is certainly a function of those choices that were made.

Certainly, we have the same opportunity in this country to make similar kinds of choices. In the 1875 time frame, the director of the Patent Office advised the President of the United States that it was a good time to close down the Patent Office, because everything that needed to be invented had been. Had the President of the United States accepted that wizened sage's advice at the time, imagine where we'd be! Yet, that was based on a calculated understanding of what folks thought was the potential of new inventions. It wasn't reached whimsically, it was reached by those who really believed that we had already incurred an enormous evolution of change of technology, revolution in industrial affairs, and, as a consequence, we were on a roll, and anything beyond that was going to be simply derivatives of the same.

In the last century, we've seen an explosion of growth in the exploration of seas, remote regions of the Earth, and, indeed, space. All of which, arguably, might not have happened had that original set of recommendations been followed.

It is no accident that NASA's founding occurred some 46 years ago this very week, in the same decade that Edmund Hillary and Tenzing Norgay first stood on our planet's highest peak, and that Jacques Cousteau used the good ship *Calypso* to conduct his epic voyages of undersea exploration. As explorers, we all share that common bond.

We dare to dream grand dreams, and, in the process of doing so, assume tremendous risk, some of it beyond the scope of our knowledge of the time in which those dreams are assumed and accepted. We do so for what we know to be great purposes. We also, in the depths of those tragedies that occur, grieve when our brethren are lost in the cause of exploration. Indeed, part of the impetus for this symposium was brought about in debates that occurred in the aftermath of the *Columbia* tragedy. It was a tough report that the Columbia Accident Investigation Board released. It told us an awful lot about the technical problems that led to it, the engineering challenges that we did not understand, and, as a result, paid an ultimate price with nine people—the seven members of the crew as well as two engaged in the recovery of *Columbia* after its destruction. We learned that that is a horrendous price—again.

But it also brought about, as a consequence of debate, a discussion about how we contributed to that tragedy, and a broader public debate about a renewal of the purpose of why we explore. And that debate has gone on in a broader public policy sense. The year after that horrific tragedy, it nonetheless was an impetus for motivating a debate by answering the fundamental question of why we explore and what the strategy and path ahead should be in pursuit of that human desire to understand.

In the process, it also raised a series of questions that we have the opportunity here, over this couple of days, to at least debate how they should be framed. We have, I think, as a consequence of the strategies the President has levied, and the direction that he has provided to us at NASA for exploration, a better understanding now of exactly how to pursue those exploration goals. And it's laid out in a series of objectives and programs to achieve it, and a stepping-stone approach, and a whole range of different ways in which we're going to achieve that task.

But communicating the *why* of this venture has just begun as a public debate in the last few months. Again, this is an extraordinary moment in time, in which there has been a renewal of that spirit of discovery and exploration. In part, it must then engage in this broader public dialogue, because we are, after all, a public organization for which there is trust that is rendered to us by the public for our acceptance of these kinds of challenges. And that trust is fragile, and at each of the intervals in which we have seen either those great triumphs or great tragedies, it has been tested.

So understanding the why, and being able to communicate that in a way that's effective, is part of what this discussion is all about. And while participating in the panel discussions, I would ask that each of us pose the following kinds of questions: How do we integrate the risk calculation with the benefits to be derived? What's the return? How do we communicate that as well?

Because it's apparent, when tragedies occur, what the depth of the risk was that was accepted, and then, therefore, not responded to effectively. But understanding what the benefits were to be derived sometimes gets lost in the translation, so how do we integrate that better? And that's on a personal as well as a societal level. There are any number of colleagues here, and those who've elected and chosen to participate in this venture, who can articulate this on a personal level. But, also, how we translate that in a broader societal context, I think, is very important, why we've accepted those risks, for what potential gain.

Also, ask the question: How do we regularly remind ourselves of the risk, and is that really important? Is it something we really need to focus on, and to what level of depth and degree? Certainly, being accepting of it or dismissive of it is not one of the options, but what is the appropriate balance? Also, pose the question: How do we avoid complacency? It is human nature, it is part of our human makeup, that what we see repetitively we begin to accept as normal? If you've never seen it before, it suddenly becomes a remarkable circumstance, something which you respond to because you've never seen it before. And, yet, it may be far less significant as risk than what you see every single day, yet, because we see it so regularly, we accept it.

What is it about our view as a culture, as a society, of why it is understood that there is a risk attendant to driving an automobile, flying in a commercial airplane? These are things we understand as being part of that, either intuitively or intellectually, and have recognized that despite the fact that lots and lots of folks every single year die in horrific automobile accidents, we accept that, as humans, because of the transportation and opportunities it provides, the facilitation of discourse and communication between and among each other, and the means to get from here to there. What is it about it that makes that an accepted level of risk?

And, yet, in the act of exploration, when the tragedies occur, what is it that makes that either intolerable or why we question it? And again, the root of this may yet well be grounded in how well we understand the benefit that we think we gained as a consequence of the activity and the effect of accepting that risk.

Also, for those who are involved in wider-ranging sets of exploration opportunities, what is it about the risk that you accept that's different than that which NASA accepts in what we do, and what is similar? How do you parse

". . . WE HAVE AN OPPORTUNITY TO LEARN FROM EACH OTHER'S EXPERIENCE SO THAT WE CAN GO FORWARD BOLDLY INTO THE UNKNOWN, INFORMED BY A RESPONSIBLE SENSE OF HOW WE COMMUNICATE IN A WAY THAT CONVEYS THE REASONS WHY IT IS OR IS NOT ACCEPTED AS AN APPROPRIATE LEVEL OF RISK."

between both and determine what we can learn from this about that? And, I guess, the ultimate question: What can we learn from each other by how to frame this question differently and, indeed, communicate it more effectively as an opportunity for great gain?

Over the course of human history every major advance has occurred because of the temerity on the part of human beings to want to understand and to explore and to do something that has not been tried or has been tried so irregularly as to have no pattern to it. If you think of every major advance in the course of our existence it has been attributed to that characteristic of us as human beings.

This week we have an opportunity to learn from each other's experience so that we can go forward boldly into the unknown, informed by a responsible sense of how we communicate in a way that conveys the reasons why it is or is not accepted as an appropriate level of risk. We are resolved at NASA to better communicate with the public about why it's necessary to take those risks, and why it is inherent in the way we, as human beings, conduct our lives in a way that would give meaning and purpose to this larger exploration agenda. At its core the answer is best summarized by a comment President Bush made in Houston just days after the *Columbia* tragedy, that this cause of exploration is not an option we choose, it is a desire written in the human heart. And when we can confront that, even on both ends of the equation—in its great triumph as well as in its depths of tragedy—and we're reminded why we're driven to this, what is it we can do responsibly as public servants, for those of us at NASA and in the broader community of explorers represented here, to communicate that more effectively?

I thank you all for your participation, and I look forward to sharing with all of you the spirit of exploration and discovery that I think is certainly evident in this group by so many people who have elected to spend their time to engage in these important questions. The manner in which we have framed this over these couple of days will bring those kinds of questions to bear in ways that, as we move forward in this next step of exploration, to return to flight, to complete the International Space Station, to develop through Project Constellation an opportunity to explore beyond Earth's orbit, all of this may be the beginnings again of an opportunity to frame that discussion and debate, not only among ourselves, but in the broader public, in ways that highlight those purposes of exploration, and why we engage in the risks and accept them, knowingly, for the purposes for which NASA began. ■

NASA Image/Renee Bouchard

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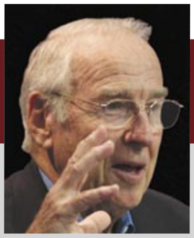
Race to the Moon

I'm an ancient mariner here and I see a lot more modern astronauts who have done a lot more than I have ever done. But I think the previous speakers have really set the scene for this discussion of how we perceive risk. Now, I would like to expand this concept of risk as it pertains to spaceflight, and, of course, Apollo 13. But before I do, let me digress and tell several personal stories familiar to me of how I think risk is perceived.

The first story takes place long before we had NASA astronauts. After World War II, Wernher von Braun came over from Germany, and he and his team went out to White Sands, New Mexico with a bunch of dilapidated V-2 rockets. Their job was to fire those rockets up into the upper atmosphere and, with the proper sensors, determine maybe what the stratosphere was like—the flow, the elements, and things like that.

But von Braun was a very farseeing individual. He knew that someday man would go into space, and he would piggyback on these rockets some experiments that would determine, or help to determine, if man could survive in the environment of zero gravity. He would put small animals in the nose cone of these rockets and put a camera at the apex. And, then, as the rocket got up to the top of its apogee and started to come down, before



James Lovell

Former NASA Astronaut and President, Lovell Communications

Captain Lovell was selected as an astronaut by NASA in September 1962. He served as Command Module pilot and navigator on the epic six-day journey of Apollo 8, man's maiden voyage to the Moon. On that flight, Lovell and fellow crewmen, Frank Borman and William A. Anders, became the first humans to leave the Earth's gravitational influence. He was spacecraft commander of the Apollo 13 flight, 11-17 April 1970, and became the first man to journey twice to the Moon. Captain Lovell held the record for time in space with a total of 715 hours and 5 minutes until surpassed by the Skylab flights.

OPENING PHOTO:
The Apollo 13 lunar landing mission crew from left to right are: Commander James A. Lovell Jr., Command Module pilot, John L. Swigert Jr., and Lunar Module pilot, Fred W. Haise Jr.
(NASA Image # S70-36485)

it reached terminal velocity, he would photograph their reaction to see how they would react in zero gravity.

Now, my story takes place out there at White Sands. One beautiful, blue day, out on the launch pad, is this dilapidated old V-2 rocket—gaseous oxygen just streaming out from the vent. Inside the nose cone there are two mice strapped tightly to their couches. This one mouse looks a little worried. His tail is twitching back and forth, and perspiration is coming out on his whiskers. He looks at his companion and says, "You know, I'm getting scared. The rocket could blow up! The parachute could fail to open! A mouse could get killed doing this kind of work!" And his companion, who had made about three flights before, said, "It beats hell out of cancer research!" So, in this particular case, this mouse figured that risk was the lesser of two evils.

Now, I'm going to tell you another personal story about this idea of risk. I'll go forward quite a bit to Gemini 7, Frank Borman and I are on a two-week mission—the purpose was to find out if man could live in space for two weeks, the maximum time to go to the Moon. And here is a case where, because of the newness of the situation, that risk was way overblown. The Gemini spacecraft proved to be a fairly decent vehicle; Gemini 3, 4, 5, and 6 were pretty good. But in those days, NASA and the doctors and the hierarchy—management—put the astronauts in the spacecraft and got them to keep their suits on all the time to fly these missions. For the first couple of missions—three and a half hours or even one day—that's fine. But, as time went on, those suits got to be more uncomfortable all the time, you know, oxygen flowing through the body, drying up the body pretty badly.

So by the time Gemini 7 came around, a two-week mission, we were determined that we were going to get out of our suits. We had a special suit but it was still bulky and uncomfortable. So we took off—and the first thing we then wanted to do was get out of the suits. We found out that the spacecraft's integrity was there. Nothing was leaking. Everything was fine. Management said, "No. No—stay in those suits." We said, "But everything is going fine here." Finally, out of desperation, I had unzipped my suit and I had snuck out of it (or almost), and I was out of my suit in everything but name. Poor Borman was still in his suit, and I could see he was getting more tired and difficult. And, finally, after about three and a half or four days, we finally got permission to get out of the suits.

So, here's a case where the risk was overkill. I mean, we knew the spacecraft was good. We knew the best way to fly was in our underwear, not the suits. And now, of course, as you and I see on TV, on the shuttle flights they're in shorts and T-shirts, so that's the way that goes.

And then the third little story I want to tell you about risk is one that you all know, but I think it's a classic. And it was the Apollo 8 flight. Apollo 8 was going to be an Earth orbital mission—around the Earth to test the Lunar Module and Command Module before we'd ever commit those two vehicles to go to the Moon. And as you know, two things happened in the summer of '68. Number one, Grumman Aircraft finally bit the bullet and said, "Hey, we're not going to get this Lunar Module ready before 1969." And then again, we had intelligence information that the Soviets were going to put a man around the Moon, a circumnavigation flight around the Moon, before the end of 1968—in fact, in the late fall of 1968.

And, as a matter of fact, we know now, talking to them and with everything in the open, that they were very serious about it. Their N-1 big lunar rocket was a failure, but their Proton and Zond probably could have done the job. And, so, I think in the fall or summer of '68, they sent Zond 5 around the Moon with small animals. I think the reentry was so steep that the animals died, but it was a test that they were doing to see if they could put two cosmonauts around the Moon. They sent another spacecraft—Zond 6 Proton went around the Moon again. And while that flight was not a complete success, it had the possibilities of success.

And here's where the change took place. In the Soviet Union, the hierarchy—the management—was arguing: "Is the risk worth the reward of beating the Americans at least to get two guys around the Moon, or should we send another unmanned or animal-bound flight around the Moon before we commit to the people?" Leonov and Makarov, the two cosmonauts, were all set to go. They were arguing: "Let's go." Other people said no.

SO HERE WAS A CASE WHERE WE ANALYZED THE RISK AND WE THOUGHT THAT THE REWARD—THE ACHIEVEMENT AND THE ABILITY TO CONTINUE THE APOLLO PROGRAM FOR LANDING—WAS WELL WORTH IT.

And while they were hesitating—while they were vacillating back and forth—a bold decision was made in this country, in the fact that the Lunar Module was not ready, but Apollo 7 showed that the Command Service Module could last for 11 days. And so, the decision was made to send Apollo 8 around the Moon and to look for landing sites and things like that.

So here was a case where we analyzed the risk and we thought that the reward—the achievement and the ability to continue the Apollo program for landing—was well worth it.

So, let me first state that everything in life involves a degree of risk—and I think I've mentioned that before—from the moment we are born until we die. And the risk can involve physical, financial, or emotional factors. You know, the Hollywood stuntman has to weigh the reward for his efforts to the risk he faces. The investor faces a risk of financial gain or loss. And, certainly, when we get married, the emotional risk is there for a happy marriage or a quick divorce. Therefore, when we have control of our destinies, such as an active space program, we must analyze the reward we achieve for the risk involved and the action we must take to minimize that risk.

In the space program—at least the one I knew—we approached the risk factor in many ways. First, the contractors, of course, set standards for maximum reliability—99 percent, if possible. And they used the concept of redundancy, you know—one of this or two of this or three of that. In case one failed, we had backups. Every effort was made to simplify space system design. One example: In the Lunar Module propulsion system, pressure-fed fuel systems were used instead of the more complicated pump systems. We incorporated escape systems. Our design of the trajectory to the Moon—the first part—would be a free-return course. That meant if the spacecraft's main engines failed in its inflight test, the spacecraft would be on a course that would take it to the Moon—and the Moon's gravity would aim it back towards the Earth. And by using only the spacecraft's attitude rockets, it could safely land back here on Earth. Thus, an added safety factor was given to the mission.

Of course, the intense systems training by the Mission Control team and astronauts was essential—including an analysis of possible failure modes and training to recover from them. Now, this training pointed out the limits on efforts to reduce risk in an Apollo mission. We only trained for single-point failures. Had we tried to train and develop recovering techniques for all possible combinations of failures—well, we'd still be at Cape Canaveral waiting for the first takeoff. And therein lies the problem between risk and reward.

I guess the best way to visualize this, at least from my point of view, is to picture a simple X/Y graph—a plot. Let's say that at the top of the Y, the ordinate at the top, is a factor up there saying "maximum risk." And then as we gradually go down the Y ordinate, the risk decreases all the way down until we get down to the juncture of the Y and the X graph—and there, theoretically, is zero risk. On the X axis, we put all those factors that we might be able to make in terms of cost—those factors that we can put into a spacecraft that would reduce risk—high reliability, redundancy, extra safety equipment that would cover any failures, true training, et cetera.

I kind of think that as we plot the graph going down, that the risk would decrease very rapidly until we got to some point where it would start to flatten out and keep parallel, never getting down to zero risk. As a matter of fact, I also think that had we continued to go out, adding additional redundancies, adding other equipment to handle other failures that might occur, and giving the crews more intense training, more procedures that they had to follow in case there are certain things that go wrong, that the risk factor would actually start to go back up again. Therefore, there's got to be a point whereby we can develop a system that we minimize the risk but without going overboard, because eventually you'll compromise the spacecraft's ability to complete its assigned mission.

Now, I think we did a fairly decent job in weighing the acceptable risks with effort to reduce risk in the Apollo program. The first six Apollo missions proved that. On Apollo 11, Mission Control quickly resolved the landing radar problem. The brilliant analysis by John Aaron saved the Apollo 12 mission after a lightning strike on takeoff. And so, by Apollo 13, Mission Control people and spacecraft crews were confident that they could handle any situation. There was, however, a wild card in our assumptions, and it surfaced on 13. Now Apollo 13 was the third lunar landing mission and strictly, I think, the first scientific flight. It was targeted to land in the hills surrounding a crater called Fra Mauro. The scientists thought the lunar material there would be different from that in Apollo 11 or 12 and, of course, we thought the surface there would tell us about the interior of the Moon.

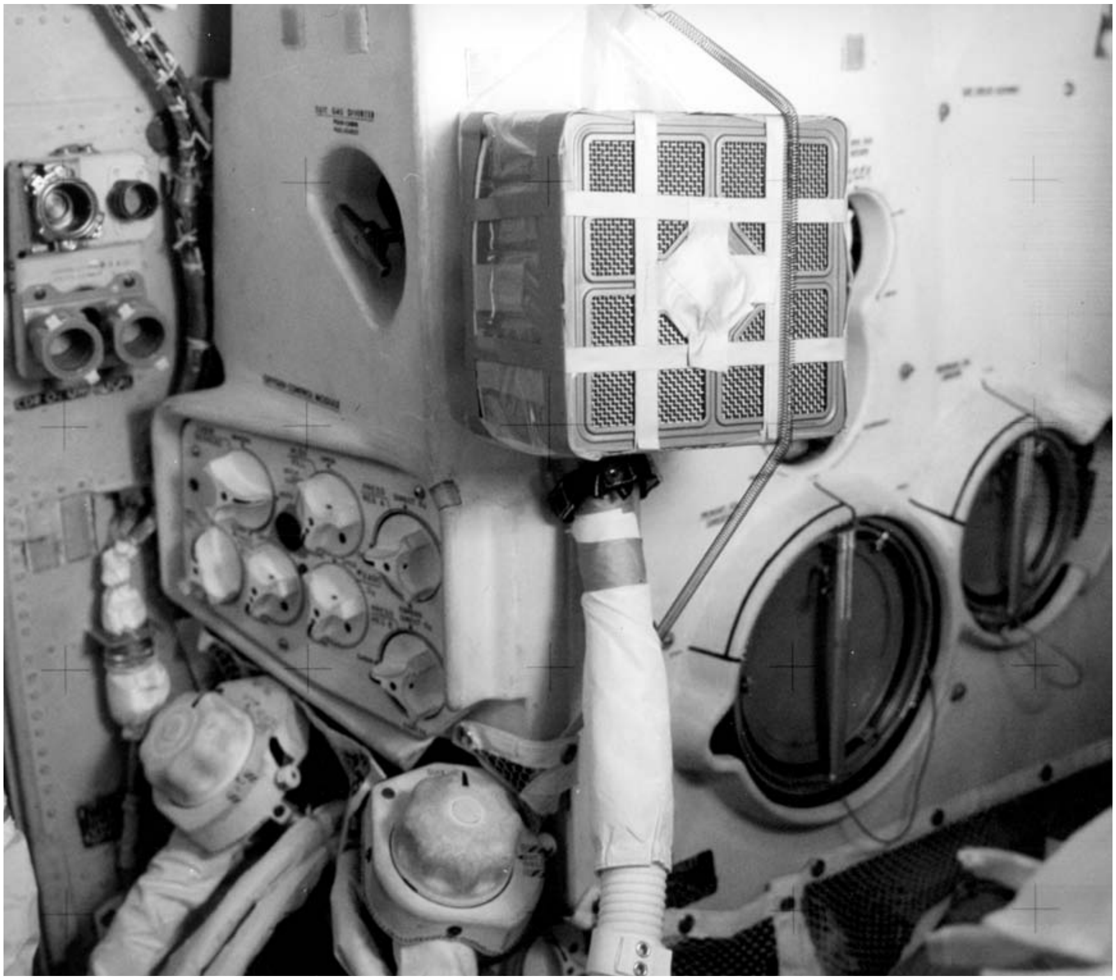
The launch occurred on April 11, 1970, at 13:13 Central Standard Time. Perhaps the spacecraft number and the time was sort of a premonition of the events to come. During launch phase, our first crisis occurred. The center engine on the booster's second stage shut down two minutes early due to a "pogo effect" or extreme oscillation on its structure. Now, this pogo effect was noticed in one of the booster's unmanned flights.

To reduce the risk in this area, an engine shut-down device was added to prevent the engine from going divergent and disintegrating. In addition, the booster was slightly overbuilt to allow a one-engine failure. Here was an example of added safety features to reduce the risk of a flight. Our initial trajectory to the Moon was that free-return course that I mentioned. But at 30 hours after launch, we changed our flight path to what we call the hybrid course. Now this was necessary to provide the proper visibility for a safe landing in Fra Mauro. And here is where we traded the reduced risk of a safe return home for the guarantee of a good visibility. Should our spacecraft engine fail now, our closest point of approach to the Earth on our return would be about 2,500 miles out. Much too far out for a safe capture by the Earth's atmosphere.

We didn't worry about it. Fourth flight—second time to the Moon—and I was getting complacent.

The explosion took place two days and 200,000 miles from Earth, resulting in the loss of all the oxygen, electrical power, and propulsion of the Command Service Module. At this point, the flight of Apollo 13 changed from another thrilling space adventure to a classic case of crisis management. It was here, too, that other factors came into play to reduce the risk involved in spaceflight.

These are the attributes, or human characteristics, of a well-trained Mission Control team: good leadership—not just at the top—but throughout the organization, leadership that develops teamwork among all those involved, including contractors; use of initiative to find solutions to problems never contemplated or trained for; the ability to focus and persevere to find the right solution for each crisis; and, of course, a team that was well motivated to get the job done. Now, these are the ingredients that turned Apollo 13 from an almost certain disaster into a successful recovery. Mission Control and the flight crew worked together to configure the Lunar Module into a lifeboat. The crew successfully transferred the controls to the Lunar Module just as the Command Module died. Procedures were developed to use the Lunar Module landing engine to put the spacecraft back on a free-returning course.



An interior view of the Apollo 13 Lunar Module and the “mailbox,” the jerry-rigged arrangement the Apollo 13 astronauts built to use the Command Module lithium hydroxide canisters to purge carbon dioxide from the Lunar Module.
(NASA Image # AS13-62-8929)

Let me digress a little bit on this. There is something that I had learned in the space program, based on what I am about to say, that I took with me from the public sector into the private sector: Always expect the unexpected. When everything is going right—when everything looks rosy, when nothing is wrong—it’s always nice to look ahead to see if there are symptoms coming down that maybe are pending for a possible crisis.

When I started to maneuver—now remember, I have two spacecraft mated together and I’m controlling from the Lunar Module, and remember, also, that I spent many, many hours in simulators learning how to fly a Lunar Module. But when I put an input in to make a certain change of attitude, the spacecraft didn’t respond that way. I couldn’t figure out why. If I wanted to go down, it went up. If I went left, it went right. I mean, after all these hours! Well, then it dawned on me. I had a 60,000 pound dead mass attached to the Lunar Module , the Command Service Module, which, of course, we needed to get back into the atmosphere. The Lunar Module had never been designed to be maneuvered with the Command Service Module attached. We had to quickly figure out how an input would give me the right output to get to the proper attitude to make that burn to get back on the free-returning course.

Now, again, it was discovered that the crew was being poisoned by their own exhalations. The round canisters in the Lunar Module to remove the carbon dioxide were becoming saturated. In the dead Command Module there were plenty of unused, square canisters.

Using their initiative, the crew systems division thought up a way to use tape, plastic, cardboard, and an old sock to adapt a square canister to the Lunar Module. This removed the over-abundance of CO_2 in the Lunar Module and, of course, prevented the poisoning of the crew. And, so, there was another little incident in system design. Why we had square canisters in the Command Module and round canisters in the Lunar Module, I will never know to this day.

Throughout the return home, the risk of disaster decreased and the odds became more positive as each crisis was analyzed and a solution developed. When it became apparent that the spacecraft would miss the narrow return corridor for a safe landing, a procedure was used that was developed as a last ditch measure for Apollo 8. I was on that flight as a navigator, so I happened to know about it. Using the Earth's terminator as a guide, a seat-of-the-pants manual maneuver was accomplished to put the spacecraft back on proper course. Again, proper training, including an analysis of how to make course changes after experiencing navigational failure, saved the day.

If, in the development of the Apollo program, we carefully balanced the risk versus the reward of a lunar landing by incorporating such factors as extreme reliability, redundancy, simplification, and intense training to reduce the risk, then what happened on 13? Apollo 7 through 12 succeeded in doing their missions, and the problems they encountered were easily solved by Mission Control working with their crews.

The answer is human error. It's a virus that can be embedded in the best laid plans. Those of you familiar with the causes of aircraft accidents will understand that most accidents are caused by a series of events that overcome the pilot and/or the aircraft. Such was the case with Apollo 13. The first event occurred about eight years before Apollo 13 took off. NASA ordered all Apollo contractors to make their electrical systems compatible with the 65 volt DC power available at the Kennedy Space Center—even though the spacecraft were designed to fly with a 28-volt DC power system. That would simplify the testing at KSC. The contractors complied with this request with one exception. A thermostat, part of the heater system inside the oxygen tanks, was not exchanged for one that could handle the high voltage. The job of the thermostat was to protect the tank from overheating. When the temperature rose to about 80 degrees Fahrenheit, the contacts would open, shutting off the heater power. At 65-volts DC power, however, the contacts could be welded shut, thus bypassing this safety feature.

All tanks on Apollo 7 through 12 had this anomaly, but none experienced the sufficient heater operation during testing to damage their thermostats.

A second incident occurred during the oxygen tank manufacture. A tank, designated for Apollo 10, was dropped at the factory. It was retested for flight qualification, but, because of the lost time, it was reassigned to Apollo 13.

Several weeks before the launch of 13, the third incident took place. With the booster, the spacecraft all assembled on the launch pad, a countdown demonstration test was performed, making sure that all the components were ready for launch. The test was successful, but after the test, the ground crew could not remove the liquid oxygen from one of the spacecraft tanks. A review of the history of the tank revealed the damage incident at the factory. Studying the design of the tank indicated that, although the tank performed perfectly for

> "... IF YOU'RE GOING TO HAVE AN ACCIDENT ON THE WAY TO THE MOON, OUR RESEARCH SHOWS BE SURE YOU HAVE IT 200,000 MILES OUT."

all inflight operations, the fall could have impaired the ground crew's ability to remove the oxygen after a ground test.

To replace the tank would slip the launch by a month, and so the decision was made to use the tank's heater system to remove the oxygen by boiling it off. The procedure was successful, but as the level of the liquid oxygen decreased, the temperature rose. At 80 degrees, the contacts of the thermostat started to open to shut off the power. The high voltage welded them shut, and the thermostat, instead of shutting off the power, became a conduit to keep the heater system on. We know now that the temperature rose to about 1,000 degrees Fahrenheit, severely damaging the heater system. The problem was not detected. When the tank was filled with liquid oxygen, it was a bomb ready to go off. It exploded two days later, 200,000 miles from Earth, when we turned on the heater system.

I might digress another little bit here because, in all this discussion of risk, there is a factor that's called fate, luck, or something like that. This was the third time we turned on the heater system; nothing happened the first two times. If something happened the first time we turned on the heater system and that explosion occurred, we would never have had enough electrical power to get all the way around the Moon and get back home again, as we had already put the velocity on to go to the Moon.

If it did not explode when it did, but waited until we turned on the heater system later, once we were in lunar orbit or when the Lunar Module was on the surface, we would never have had enough fuel in the Lunar Module to either get out of lunar orbit, or get enough to get back home again.

So, if you're going to have an accident on the way to the Moon, our research shows be sure you have it 200,000 miles out.

I asked Gene Kranz, who was the lead flight director, what lessons he learned from Apollo 13 that could be applied to the Mission Control team—and maybe all of NASA. Here are some of his comments: Develop the chemistry of a winner. The mind-set for success must be embedded in the values and culture of the organization. Be positive. Be optimistic. Do the right thing the first time.

A second comment that he made: articulate a common vision that focuses your energies on your objective; team focus to accomplish the mission, whether it is in crisis mode or whether it's the entire organization. This was outlined by the President just recently. We must focus our energies on accomplishing that mission.

The third thing he mentioned: teamwork provides the multidisciplinary capability to deal with complex and fast-moving problems. We can say many brains are better than one. Get the team together. Think up the solution. And, I kind of think, when I look back now on our Apollo program, that this was pretty common throughout our entire NASA organization. We had good leadership at Headquarters. Marshall did the booster. Goddard did the network. Johnson did the spacecraft and the crew training. Kennedy did the launch and the integration of the whole thing. So, we had a pretty good team.

Fourth, Kranz says: build momentum quickly. This allows rapid response to limit problem growth. I think what he means there is that a quick response will give an insight to head off future problems that might be the result of an original problem.

He also says: be flexible. Solutions often lie outside the box. The idea there was the carbon dioxide incident on 13.

And then he says also: don't get distracted, and don't let your team get distracted. For Apollo 13, on that particular flight, when I was waiting for the information to come up to re-energize to get the Command Module back in operation again, there was delay after delay, and I thought that they were going to set up more information to find out what went wrong and give us more things to do than just get the spacecraft ready. I didn't want the crew down there at Mission Control to be distracted. I needed those basic procedures to get the Command Module going again.

He then says: overwhelm the problem. Use every available asset. As soon as you have one, call in everybody who has any idea of what may be happening, almost like verbal popcorn, but then you can winnow out what is good and what is not good.

Finally, his idea is: keep the poise. Let your words and actions convince your team that you are controlling events. Good leadership. You saw the movie. Gene Kranz, like Ed Harris when the whole Control Center is talking about finding out what went wrong when they found out about the explosion, says, "Stop guessing. Stop guessing. Let's work the problem."

In our approach to accomplish the President's directive of revisiting the Moon and on to Mars, we must accept a certain amount of risk and realize that unforeseen events are always present. The strategy of spacecraft development and mission design is to minimize the risk without compromising the goal. Whenever you are involved in an operation that handles thousands of pounds of high explosives, reaches extreme velocities, operates in a vacuum environment under zero gravity, and then encounters tremendously high temperatures on return, you are, if I can borrow the title from one of Tom Cruise's old movies, in a "risky business." The people involved in that business and those who monitor, critique, and investigate the results, should recognize that fact.

To be completely risk-averse is never to take off.

We should be aware that sometime in the future, we will again hear those words: "Houston, we have a problem," and I hope we'll be prepared to meet the challenge. Or, if I can steal the words from Gene Kranz, "failure is not an option".

NASA Image/Renee Bouchard

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Bold Endeavors:
Lessons from Polar and Space Exploration

It is an understatement to say that it is a pleasure to be here today to talk to you about some of my research. The concept of risk is something with which we all are familiar. Every decision that we make from the most trivial to the most important is attended by some sort of evaluation and consideration of the costs and the benefits, and the likelihood of a successful outcome.

Expedition risk is of a different order. And humans are not particularly good at estimating risk. The research shows that we have a tendency to underestimate risk over which we have some control, and to overrate risk over which we have no control. That's why we take the risk of driving on the highways, where presently there are 1.5 fatalities per 100 million miles traveled—incidentally that's down from 5.5 fatalities per 100 million miles traveled in 1966. You were four times more likely to die in a traffic crash 30 years ago than you are now, and there are nearly twice the number of automobiles and vehicle miles traveled. We've done a lot to reduce risk in certain areas.

But why do nations and individuals explore? I have here just a partial list. Trade routes, looking for new resources, in some cases national prestige, and, of course, science. Individuals explore sometimes to satisfy a need for achievement, to do something special,

Jack Stuster

Behavioral Scientist and Vice President and Principal Scientist, Anacapa Sciences, Inc.

Jack Stuster's work for NASA has included a study of Space Shuttle refurbishing procedures and studies of conditions on Earth that are analogous to space missions, including an analysis of diaries maintained by the leaders and physicians at French remote duty stations in the Antarctic and on small islands in the South Indian Ocean. He has developed design and procedural recommendations to enhance the habitability of the International Space Station, future spacecraft, and planetary facilities. Stuster completed a study of Antarctic winter-over experiences, expeditions, and voyages of discovery, which are documented in his book *Bold Endeavors: Lessons From Polar and Space Exploration*, published in 1996 by the Naval Institute Press.

OPENING PHOTO:
Replicas of Christopher Columbus's sailing ships *Santa Maria*, *Niña*, and *Pinta* sail by *Endeavour* (orbiter vehicle 105) on Kennedy Space Center Launch Complex Pad 39B, awaiting liftoff for its maiden voyage, STS-49, on 7 May 1992. (NASA Image # S92-39077)

many times out of curiosity, including scientific curiosity, and I truly believe that some people explore because they need to accept risk. Life just isn't enough without taking some chances. However, taking calculated chances is far different than being rash.

Every bold endeavor that I've read about was accompanied by naysayers, people who predicted that the expedition would result in disaster. It's archetypal that Columbus had difficulty finding the financing for his planned expedition. It wasn't because people believed the world was flat. By 1492 all learned people knew that the world was a sphere. The circumference of the Earth had been calculated by the Greeks, and then again later, and accurately, 400 years B.C. or so, and again later, but the later estimate was off by a large factor.

Columbus believed that he would reach Japan after traveling about 3,200 miles west. He was right. He did make landfall 33 days after leaving Spain. But had he known that it was really 10,000 miles to Japan, and that a continent or

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two interrupted his voyage, he might not have taken that risk. He did maintain two journals, one for his own use, and one for the crew that showed they were making far greater progress than they actually were—a way for him to minimize his personal risk on board.

There are many justifications for exploration. One of my favorites is from Fridtjof Nansen, a Norwegian explorer, that might seem appropriate in this age when people complain about spending money on space. I mean—the critics say we should spend it here—as if the money were actually taken into space and thrown out of the spacecraft. But Nansen, who was a scientist as well as an explorer, wrote that "people perhaps still exist who believe that it is of no importance to explore the unknown regions. This, of course, shows ignorance. The history of the human race is a continual struggle from darkness toward light." I think that's beautiful. "It is therefore to no purpose to discuss the use of knowledge. Man wants to know, and when he ceases to do so, he is no longer man." I think that says it all. And also, Nansen was an early supporter of women's suffrage, so please don't judge him by his 19th century usage of the term 'man.'

Roald Amundsen was a little more blunt in saying that "Little minds only have room for thoughts of bread and butter." But I will talk more about both

Nansen and Amundsen in a few minutes. There are many things I want to talk about that I'm sure I'm going to forget, so forgive me for that.

Robert Falcon Scott wrote, after his first expedition to Antarctica, about how ill-prepared they were. "Not a single article of the outfit had been tested, and amid the general ignorance that prevailed, the lack of system was painfully apparent in everything." Robert Falcon Scott gave great advice about things, but he didn't really take his own advice. In his final hours, having reached the South Pole in 1912, only to find that Roald Amundsen had been there 30 days earlier, and on the trip back, laying in his tent with comrades who had perished beside him, he wrote in his journal that "We took risks, we knew that we took them. Things came out against us, and therefore, we have no cause for complaint."

Scott was unlucky also. They perished only 8 miles from the supply depot that had been prepared for them. They just couldn't get to it in the storm—1912 had been an unusually stormy year in Antarctica. Under other conditions, they might have made it to the depot and come home to write an account of their expedition.

Apsley Cherry-Garrard, who was also a member of Scott's expeditions, wrote that "the members of this expedition believed that it was worthwhile to discover new land and new life, to reach the South Pole of the Earth, to make elaborate meteorological and magnetic observations and so forth. They were prepared to suffer great hardships, and some of them died for their beliefs."

They should have been more prepared. Others were. Scott used Manchurian ponies, which didn't really cut it in the snow, nor had they ever tested the tractors they took to Antarctica. There was a certain hubris involved. Amundsen used dog sleds. The British would not use dogs or skis. It wasn't British. They were going to slog it out.

Most of my work has involved the risks associated with the psychological, behavioral, and human aspects of isolation and confinement. I use the following analogy to help people get a handle on what it would really be like to be on an expedition to Mars. Imagine living in a motor home with five other people for three years. You're driving around the country, and you really can't get out for about a year, and then, when you go outside, it's for very brief periods, and you have to wear spacesuits, and you come back, and then you spend another year or so driving around with those same five people. You've already heard every story that they've ever told. The days blend one into another. The condition becomes mind-numbing, and the tiniest, tiniest things get on your nerves. It is characteristic of all conditions of isolation and confinement that trivial issues are exaggerated way out of proportion. Everyone who I've interviewed about this talks about how they would have an incredible argument at an Antarctic research station over a fax transmission or something, and blow up, and then an hour later wonder: "What the heck happened? What was that all about?" It is a universal occurrence.

One of the other universals of isolation and confinement is the strange relationships that occur with your Mission Control, with your headquarters, wherever it is located—in Antarctica, it might be Port Hueneme, or it might be the Johnson Space Center or elsewhere. But the remote crew always gets the impression that "They really don't understand the conditions under which we're operating. We're trying to get a job done here and they're not responding fast enough." Or, "They're giving us too much to do." It always happens. And, you know, I used to think that it was just endemic to isolation and confinement, but I think it's a structural condition. Even the field offices of a corporation, a small one or a large one, or perhaps the research centers of a major government agency might feel these same sorts of tension. It is just a natural phenomenon that occurs. If you're prepared for it, you can somehow reduce the risk.

Anyway, an expedition to Mars would be a lot like this metaphor that I've described for you. The first research that I conducted for NASA was conducted for the Ames Research Center. In 1982 they took a chance on this anthropologist who was working in the field of human factors to study conditions on Earth that are analogous to what we expected for future space crews. I studied conditions such as offshore oil platforms, commercial research vessels, fishing vessels, fleet ballistic missile submarines, saturation divers, and so forth, and came up with 100 or so design recommendations. It's my understanding that a couple of them actually made it to the final design of the International Space Station, for which I'm grateful. I would like to know which ones they are. Personal sleeping quarters I don't think has made it, and that was one of the most important recommendations.

More recently, I've conducted research through the Johnson Space Center concerning longer-duration missions, one year to three years. The only analogues available for such a long mission are previous expeditions. And, of course, I included our experience with Skylab, and there is much of relevance from Skylab.

NASA has a tradition of trying to learn from the past, and in many cases is successful. However, I remember reading in one of the industry publications that: "One of the great lessons from the NASA experience on board *Mir* was that you really shouldn't hard-schedule everything. You should have this task list that you put things on. And then the crew can go and take from that task list as necessary. Isn't that a wonderful thing?" I thought: My gosh, that was the principle behavioral finding from Skylab. Didn't anybody read those wonderful lessons learned reports from Skylab?

So, I wrote a letter to the editor, and I probably angered a whole lot of people in doing so, but there is a lot that we can learn from the past, including our own more recent past.

I've found that expeditions, and polar winter-over experiences in particular, resemble in many ways what we can reasonably expect for future space crews. Chronologically, the earliest of the expeditions that I studied was Columbus's first voyage of discovery. And although it was only 33 days out to the New World and seven months total, there really is a lot to learn from that experience. For example, he had strong-willed subordinates who questioned his authority regularly. One of them [Pinzon, commander of the *Pinta*] left the expedition in search of gold to the north, leaving the two principal vessels.

And it's probably not well known that on Christmas Day, 1492, the *Santa Maria* went ashore and was broken up. The reason was the crew had partied the night before, celebrating Christmas Eve, and left the watch to a cabin boy who didn't know what to do when the ship slipped its anchor. No one was killed during the process, but it left Columbus with only one hull.

Columbus believed in triple redundancy long before it was a NASA policy, and he probably would not have left Europe with fewer than three hulls, and certainly would not have returned. Oddly, in one of those incredible coincidences that occurs that I've read about in the history of exploration, Pinzon rounds the bend of this little island—this tiny island where the crew was trying to decide what to do. Would they be able to rebuild and make a small craft out of the remnants of the *Santa Maria*? And then Pinzon shows up. They were able to return home, but in the two smallest of the three craft.

Redundancy is an important method for reducing risk and increasing reliability. There are other methods: overbuilding—you build the valve to withstand 150 percent of what you expect it to withstand; graceful degradation, so that you have time to do something about it; and maintainability. When you have a human crew, you should really take advantage of the crew for maintainability.

One of my favorite explorers is the French explorer, Jules-Sébastien-César Dumont d'Urville. Early in his career, he was on the island of Milos when people approached him about a statue that was hidden in a cave. He saw it and wanted it for France, so they dragged it down to the ship, breaking off two arms in the process. It's what we know as the Venus de Milo. Later in his career, he commanded two expeditions to the Pacific and to Antarctica. He was one of the first to see the mainland of Antarctica, which he named Adelie Land for his wife, whom he rarely saw. He also named the linguistic groups of the Pacific with the names that we use today—Polynesian, Melanesian, Micronesian. He was an exceptional leader. At a time when expeditions—naval ships, in particular—were commanded autocratically, he was a kind and generous captain. He dressed as the crew did, which perplexed the British any time they met, because they didn't understand. They didn't believe he was truly the captain when he was wearing a straw hat and an open shirt. He was a realistic man.

On his second expedition, he was required to leave Marseilles carrying plants to the South Pacific. I don't know exactly what the plants were, but he had lots and lots of plants. At first, he objected to it because they were in pots and all over the ship, including in his cabin. And, after a week at sea, he wrote in his journal that this was a wonderful addition to an expedition and, if he had his way with things, every French ship that left port would be accompanied by plenty of foliage and greenery inside. I think that that's not too dissimilar from some of the comments that we've heard from space crews loving to spend time with the growing experiments on board.

The French had discovered early on something that was very painfully learned elsewhere, and that is, that there's often conflict among subgroups in an isolated and confined situation, and there were a lot of problems with the civilian scientists and the military crew. The scientists were outside of the command structure and it was always a problem, which led to the demise of some expeditions, or contributed to it, at least. So the French would take bright Naval officers and train them to be botanists or natural philosophers and artists.

It's particularly appropriate that we talk a little bit about the Lewis and Clark expedition in this year of the bicentennial. And there is much to learn, even though there are great differences. It was all outdoors, for one thing, and not in a confined environment, except when they were in winter quarters in Oregon where it was raining all the time. One of the things that we can learn from the Lewis and Clark expedition is to establish a spirit of the expedition. Thomas Jefferson named it the "Corps of Discovery"—a brilliant thing to do. I was very pleased in 1999 when I visited the Astronaut Office at Johnson Space Center and saw a sign that read," Expedition Corps." I asked, "What is this?" Andy Thomas responded, "Well, it's for the people who are planning to go to the International Space Station and beyond." I said, "It's a stroke of brilliance." You have people already using the mind-set that this is an expedition. It's going to be a long time—it's not a test flight, it's really an expedition. It's my understanding that Michael Foale is responsible for doing that. [Foale replied that astronaut Ken Bowersox (also in the audience) was responsible for the use of the term]. Well, it was a stroke of brilliance and should be congratulated. It's a wonderful idea. It helps people get in the mind-set for an expedition.

There were 40 explorers with Lewis and Clark. By the way, only one member of the expedition perished in the entire three years, and he died of a burst appendix, we believe, based on a description of the incident. Any one of you who ever had acute appendicitis would probably agree with me that you'd want to have that out before you go. Now, the physicians tell me that that's not necessary, but, from my experience, I wouldn't want to have that condition a long way from home. The Lewis and Clark Expedition was 28 months long, about the same as an expedition to Mars might be.

Lewis and Clark and their company met many native peoples along the way. That probably won't happen on a mission to Mars, although some people are hoping for it, I'm sure. But one thing that they did was to describe everything in their journals. Captain Clark and Captain Lewis were meticulous journal keepers.

I thought it might be interesting to find out what exactly they were doing on the 27th of September 1804—200 years ago today. I was amazed. It was the most pivotal period of the Lewis and Clark expedition. Two days ago, they were on the Missouri River, and they reached a tributary near what is now Pierre, South Dakota. They had finally encountered the Teton Sioux, who they had heard were going to be hostile to them. Indeed, it was a three-day period of intense hostility. They had learned through interpreters—through other Native Americans—that the Sioux intended to prevent them from going any farther and to steal all their stuff. The two preceding days were just incredibly tense.

On the 27th, they were trying to leave the village, and the little boat that was taking them out to the larger keel boat had lost its anchor and was having trouble maintaining its position. The little boat came out and parted the remaining cable, and there was a lot of hollering to get the people to their oars and so forth, and that alarmed Black Buffalo on shore, so he called all 200 of his warriors out to the shore. Lewis and Clark believed for sure that this was going to be the showdown. They went to stations—Clark went to the bow and manned the swivel gun, a little two-inch cannon loaded with shot. They had something like 20 men with blunderbusses loaded with shot trained on the main body of the group. They had a technological edge here. They would have wiped out 40 or 60 of the Teton Sioux, but there's another 200 of them in arrow shot, and they could keep an arrow in flight at all times, and it's a long time to reload the weapons on board the keel boat.

There was this standoff for we don't know how long, but it appears to be quite a while, with Clark in the bow shouting, the interpreter, who really didn't speak Teton Sioux, trying to convey to Black Buffalo to control his people

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because there were warriors who were coming into the water, who were grabbing hold of the mast of the little boat to keep it ashore. They thought for sure that this was the incident that they had been fearing. What Clark didn't realize was that his people obeyed him because it was a military organization. The Teton Sioux were only recently a tribal organization. It was a group of bands that came together when the resources permitted. Black Buffalo's control over the 200 or so was based on his charisma—only a quarter of them were related to him and had some obligation to obey him. But Clark took a risk that if he held his ground and didn't fire, it would be resolved peacefully. And the decision paid off. Finally, Black Buffalo pulled on the arm of one of the guys and apparently told him to back away, and the Corps of Discovery was permitted to go.

Of course, the Sioux dogged them all along the way, trying to get them to come ashore or to take them on board, which Lewis and Clark didn't do. I'd just like to read a sentence or two from the journal entry for this day 200 years ago. "We were on our Guard all night. The misfortune of the loss of our Anchor obliged us to lie under a falling bank, much exposed to the accomplishment of their hostile intentions . . . Our Bowman, who could speak Maha, informed us in the night that the Maha prisoners informed him we were to be stopped. We showed as little signs of this Knowledge of their intentions as possible. All prepared on board for anything that might happen. We kept a Strong guard all night, no Sleep. Captain Clark, 27 September 1804." Just south of the Mandan villages is where this all occurred 200 years ago today.

The lessons applicable to the future? The importance of good leadership. Previous studies found that good leadership is actually more important than good habitability. Plan everything. Have a sense of cooperation and perseverance. To the extent possible, live off the land. Now, you won't be able to hunt buffalo on Mars, but you will be able to use the resources on Mars in the same manner to extend your reach. And, of course, develop a spirit of the expedition, symbolized by the Corps of Discovery.

Another expedition that everyone knows about is the voyage of the *Beagle*. It was really a British surveying expedition, the purpose of which was to chart the coastline of South America. Captain Robert Fitzroy was—I can't think of a polite word to use—a very stern and narrow-minded person. He at first didn't want the volunteer naturalist, Charles Darwin, on board, because he didn't like the look of his nose. And then later, off of the coast of Argentina, Darwin had an argument with Fitzroy and almost abandoned ship, because Fitzroy thought that slavery was a noble institution and had a lot going for it and Darwin thought it was disgusting. And, so, at their next port, Darwin spent several weeks on shore until he cooled off.

Darwin wrote in his journal about the crowded conditions on board a research vessel. So many chronometers and so many people packed into small space. It was a very difficult journey for him. Darwin, after this five-year voyage and returning to England, lived to be a very old man. But he never again set foot on a boat, never again left England.

One of the most relevant expeditions is the Belgian Antarctic expedition of 1898–1899. It's relevant not just because it was the first expedition to winter over in Antarctica, the first expedition to really have science as its true objective in Antarctica, but because it was a multinational crew, cosmopolitan, and, in this regard, truly modern. It included Norwegians, Romanians, and, of course, Belgians. They had the very best of all French food, and one American, Frederick Cook, the ship's physician.

What happened on board the *Belgica* is well-documented. The crew gradually slipped into a malaise that was paralyzing to some of them. One man died because of what Cook thought was the effects of the isolation and confinement. One man developed a temporary deafness. Another man developed a temporary blindness. One man, each night, would find a place below deck where he could hide and sleep, because he thought people were going to kill him. Roald Amundsen served his apprenticeship as an explorer as mate on the *Belgica*, and later wrote, "Insanity and disease stalked the decks of the *Belgica* that winter." He credited Frederick Cook with saving the expedition from certain psychological collapse.

Cook saw what was happening, and he thought that there was this heavy psychological component, but he also thought something was missing from their diet. This was before vitamins had been discovered, but he figured there was something missing. He tried to get the men to eat fresh penguin meat, but it tasted too fishy for many of the men. So, for those who were the most afflicted by this malaise, he would have them stand with nothing on except an overcoat exposing their naked skin to the glow of the ship's stove. He called it the baking treatment. They'd stand there for as long as they could each day, taking turns doing this. Whether it had some effect on them, or maybe it was a placebo effect, it did have the effect of helping the crew get through this very difficult period. Cook also thought that exercise would help, so he required the crew to take walks on the ice, but this devolved into a circular path around the ship that became known as the "madhouse promenade."

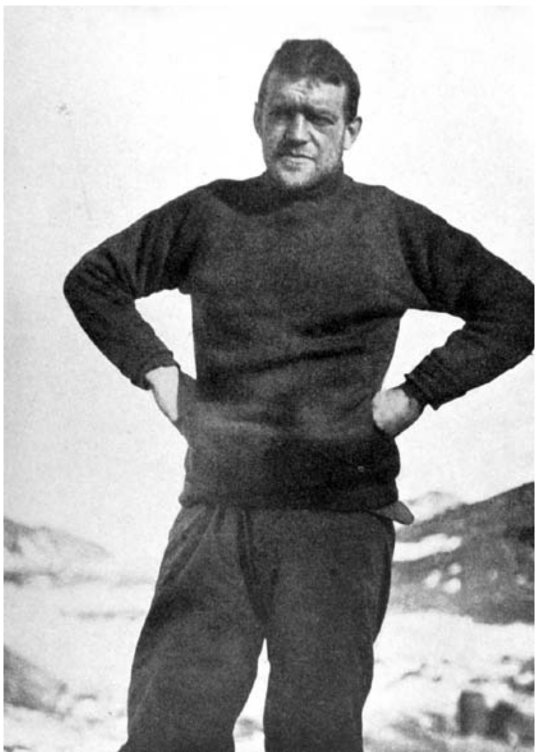
It was a dismal time, and it appeared when the spring came that they were not going to be able to release themselves from Antarctic's icy embrace. They worked very hard with ice saws and explosives and finally did break free, because they knew that they couldn't survive another year.

This is not to say that people haven't survived isolation and confinement before; many have. There were often several hundred whaling ships locked in the ice at any given time in the north during the 19th century. It is well known that during the height of the Cold War, there were 10,000 American submariners, at any given moment, at sea, in isolation and confinement.

Regarding the Australasian-Antarctic Expedition and Douglas Mawson, I formerly neglected the Australian contribution to exploration until my dear friend, Desmond Lugg, showed me that it was just a characteristic American narrow-mindedness to focus on certain things and disregard the rest. I rectified that situation by reading as much as I could about this expedition and about Mawson. There is a tremendous wealth of information that we can extrapolate from Mawson's experience. For one, personnel selection is important, and, for another, weather influences everything. It'll interrupt your plans. It will break equipment and keep you from doing things that you want to do. If you don't think that's relevant to the future, ask Michael Foale, who had on several occasions to retreat to the hardened portion of the International Space Station when there were solar events, solar weather. Also, on Mars, there will be similar solar events and solar particle events and also dust storms. Dust storms on the planet Mars can envelope the entire planet, and that would affect an expedition.

Roald Amundsen was the most successful of all explorers; he always made it to his destination. First to the Northwest Passage. First to the South Pole. In 1923 he was on two Dornier flying boats to fly over the North Pole. One of them developed problems and had to land. It crash-landed. The other one landed. They spent two weeks on the ice, leveling with wooden spoons an airfield for them to take off. Amundsen structured every moment of every day. The hours of work, the hours of eating, the hours of sleep, the hours for talking, for smoking, everything. He was in charge, and he made himself known to be in charge and organized everything. When they returned to Norway two weeks later, of course everyone thought he had died in the ice, and it was a wonderful welcome. Amundsen later perished in the North while looking for Umberto Nobile, a guy who he devoted his biography to criticizing. I work in the field of human factors, and I'm grateful to Roald Amundsen for his wonderful statement, “The human factor is three-quarters of any expedition.”

Ernest Shackleton is probably the best known of all the explorers. There are movies about him, books about him, and seminars at corporations to impart the style of leadership that he had developed. His recruiting ad from a London newspaper read, “Men wanted for hazardous journey. Small wages, bitter cold, long months of complete darkness, constant danger, safe return doubtful. Honor and recognition in case of success.” Now, this might have been a personnel selection measure on his part, because I truly believe he thought he was going to return, but he wanted to make sure that everyone who embarked with him would be aware of the risks.



Ernest Shackleton. (Source: Shackleton, E.H. *The Heart of the Antarctic, Volume I, 1909.* p.234.)

Shackleton had very clever ways of selecting people not so much on their technical expertise, but on how well they got along with their colleagues. He would ask them impertinent questions, and if they responded defensively, that might not be the kind of person that you really want in your tent eight months into a bad situation. But if they were humorous about it or philosophical about it, the person might be okay. Although Shackleton never made it to any of his destinations, he never lost a man. On the British trans-Antarctic expedition, the *Endurance* was locked in the ice, and [the] crew spent months on board, and then several months in a camp next to the ship as it was sinking. Then they moved to a camp that was on an ice floe that was as large as they could see, but, gradually, as the winter ended, the ice floe was breaking up around them. It was a mile across. Then it was several hundred yards across. Then it was 100 yards across. They had been practicing their egress to the boats. They had saved lots of equipment and three cutters from the ship. They had everything in the boats and they had practiced many, many times to escape the floe. It started to break up beneath them. It actually broke up right in the middle of the camp. Shackleton dramatically rescued one of his crew members from the ocean, pulling him onto the ice, and they departed. Then, they spent a week in these open boats in the worst sailing conditions on the planet, before they made it to a tiny rock called Elephant Island, where they made it ashore.

Shackleton knew that they could not survive there very long, so he selected five men to accompany him on the most arduous and dangerous open-boat voyage probably ever undertaken, to get to a whaling station on South Georgia Island. He took some of the people with him because he needed their skills, but he took some of the five people with him because he didn’t want to leave them there. They were the malcontents that might have made things really bad for the folks who were going to be confined to the huts they made from the overturned cutters on Elephant Island. He eventually made it to safety. They made five rescue attempts, finally getting to Elephant Island with a borrowed tug from the country of Chile. It is a wonderful story.

I want to talk just for a moment about Richard Byrd, because he's American and one of the few of the American polar explorers that I consider relevant. On his 1934 expedition, Byrd built Advance Base, a 9 by 13 foot hut that was transported 100 miles from Little America and buried in the snow. It was going to be his experiment in isolation and confinement. Originally, he intended to have two people live there, but wrote later that he didn't want to subject anyone else to the risk. He considered the primary source of risk to be the psychological risk of being alone in complete darkness. Well, he really shouldn't have done this, because he almost killed himself three different ways. He fell and injured his shoulder even before the party that had delivered him had departed. He was continuously poisoning himself from the exhaust from the gasoline generator and from the fumes from a poorly vented stove. He almost froze to death when he locked himself out of the cabin in a storm—that was poor human factors preparation, the latch on the door.

But the crew at Little America knew that something was wrong several weeks into this experiment when his Morse code transmissions were the equivalent of slurred. They mounted three different rescue missions before they got to him, and he was in terrible shape. He survived to write one of the most eloquent accounts of life in isolation and confinement at its worst in the book *Alone*, in 1938. "Time was no longer like a river running, but a deep still pool," he wrote. He also said that "a man who lives alone lives the life of a wolf." That is, his manners left him, which is something that happens in isolation and confinement

The Norwegian Polar Expedition is one of my favorites and the expedition from which we can derive the most benefit. Fridtjof Nansen would have had a wonderful career in modern times, either as a rock musician or an actor. But he was a scientist. He was one of the founders of the modern theory of neurology. He was one of the popularizers of skiing as a sport. He had skied across Norway from Bergen to Oslo. Skiing was not a sport at the time, it was something rural people did to get around.

It is difficult for us to appreciate what the world was like during the closing years of the 19th century. We take for granted a communications network and travel abilities that allow us to reach anywhere in the world. But in 1893, there were still many unknown regions and many unanswered questions of the natural world, and the most compelling was, "what is at the North Pole?" Is it land? Is it ice? Is it open ocean? There were fanciful predictions. And many people had perished trying to find out.

Nansen had a plan. There was some evidence that the polar ice pack moved across the top of the world from east to west. So he thought: if a ship were built properly, it could be locked in the ice on purpose, and then you could allow nature to carry you across the top of the world. He had a plan for a ship which he called the *Fram*. "Fram" means "onward" in Norwegian, and it was his personal motto. He approached the Norwegian government with this plan and received a grant. He had to go back, not unlike modern expeditions, because of cost overruns for building in an additional margin of safety.

During a time when crews were separated—with the "men," or crew, sleeping before the mast in the forecastle, and the officers and scientists in the main cabin—Nansen designed the *Fram* so that all staterooms opened onto the saloon, or the main area, a perhaps characteristically egalitarian, Norwegian approach. It was a very stratified society, but he did this to encourage comradeship and facilitate habitability. Nansen tested everything beforehand. There were spinoffs from his expedition. Polar travelers still use the Nansen Cooker, because it extracts the last calorie of energy from fuel.

The Norwegian Polar Expedition provided a model for all future explorers. The *Fram* sailed up the coast of Norway, across Siberia, and at a point closer to Alaska than Norway, headed into the pack ice on purpose. The ship was built with a rounded bottom and a recessed keel. Every fitting could be removed so ice could not get a purchase on this ship. When the ice encroached, and the pressures increased on the hull, the ship rose up out of the ice and remained cradled in that manner as she drifted across the top of the world. The theory was proved, and when it appeared they would get no farther north, Nansen selected one man, Hjalmar Johansen, to accompany him on a dash to the pole.

After many weeks, they found that they were only making a mile a day. So, at the closest that anyone had reached to the North Pole at that time, they turned back. They had no hope of regaining the *Fram*. They made it to Franz Josef Land where they were caught by an early winter.

Nansen knew that the secret was to keep people busy with meaningful work, and, of course, to be especially careful about the food. Norwegians are not afraid of the cold. They say there is no such thing as bad weather, only bad clothing. And he also knew that it was important to keep people entertained. The crew looked for every opportunity to celebrate. After awhile, they actually went into their almanac to find other countries' holidays to celebrate. Special celebrations break the monotony and help motivate a crew.

Nansen and Johansen built a 6 by 10 foot hut out of stones and walrus hides. Their entire world was illuminated during that Arctic winter by the pale glow of a blubber lamp. They had nothing to do. They slept sometimes as many as 20 hours out of the 24, in the same sleeping bag, because it was the most efficient way to conserve heat. But they never resorted at any time during their nine months to any sort of conflict or harsh words. This was the first thing that the press asked them when they got back. How did you survive?

They burst from their hut in the spring and performed every task that was required of them expertly, despite the mind-numbing sameness of the nine months that they had endured in isolation and confinement. They couldn't clean themselves. They had no towels. They didn't have a change of clothes. They would take their knives to scrape the soot that came from the blubber lamp that heated their food and illuminated their hut. They would scrape the blubber off and back into their lamps, recycling the fuel. It was incredible. Their dreams were filled with clean clothes and Turkish baths.

Nansen and Johansen came upon a British expedition within a month after leaving their hut, and they stayed there for another month or so until that expedition's relief ship came. The day that they stepped foot on Norwegian soil, the *Fram* broke loose from the Arctic pack ice on the other side of the world, then made its way back. The crew was united and sailed together around Norway and up Christiana fjord to what is now Oslo. They were greeted as if they had just returned from another planet. It's hard for us to imagine what it was like 110 years ago, but the similarities to the feelings that we would have are certainly there.

This artist, explorer, neurologist, oceanographer, champion skier, and founder of Norway was instrumental in the League of Nations. He received the Nobel Peace Prize for saving hundreds of thousands of lives from the Armenian situation, and also helped with a famine. The new Soviet Union after World War I wouldn't recognize the Red Cross. Nansen was respected throughout the area for his experiences, and organized a relief effort, when he found that there was a famine underway, while helping to repatriate prisoners of war. Presently, there are people in Eastern Europe who hold what is called a Nansen passport for displaced persons. His legacy is wonderful.

There is much to learn from the past that is applicable to the future. I have a lot to say about that, but I am out of time. The main themes to emerge from my research are: Certain problems are highly predictable, but they can be mitigated by taking the proper precautions. One of the most important findings is that humans can endure almost anything.

My work has focused on the behavioral and human factors issues, and I performed a content analysis of diaries that were maintained by the leaders and physicians at French remote duty stations on tiny islands in the south Indian Ocean and at the Dumont d'Urville station in Antarctica. Engineers have been asking the behavioral sciences for many years, "What's the most important behavioral issue? Is it privacy and personal space? Is it sleep? Is it group interaction? What is it?" Psychologists and others would say, "Well, group interaction." "Well, how much more important?" "We don't know."

I used content analysis to help answer the engineers' questions. The method is based on the assumption that the more someone writes about a topic, the more important it is to that person. I found that group interaction received almost twice the number of category assignments as any other category. The study resulted in the first rank ordering of behavioral issues based on quantitative data. I also found a decline in morale during the third quarter of an expedition; whether it is a 5-month mission or a 12-month mission, there is a drop, in effect. Initially, I thought, isn't this an interesting and useful discovery. Then I started to realize that it applies to almost everything. Think of a semester in college: you're only three-fourths of the way done and there is all that work yet to do, and

I've only got three weeks remaining. I think it applies to many situations in addition to isolation and confinement.

There are some specific lessons. One of them is to design for redundancy, as NASA does so well, and also for maintainability. There is no substitute for having Captain Lovell on board to take duct tape and fabricate a solution to a problem. One should expect casualties. Don't consider it out of the question. Also understand that weather will affect everything. The conditions will be different, but most of the problems that will confront future explorers will be the same problems that were confronted in the past. It won't be the gasoline-powered generator or the poorly vented stove that Byrd encountered, but some other similar situation.

We have embarked on a new age of discovery already, and there is much more in store for us—wonderful things.

One of my favorite quotes is from Arthur C. Clarke, who is one of the most prescient people on the planet. He invented the PDA for *2001: A Space Odyssey*. He invented the communications satellite, as we all know. His words inspire me. Every time there is a visible pass of the International Space Station over my house, I am out on my roof watching it. "Every age has its dreams, its symbols of romance. Past generations were moved by the graceful power of the great windjammers, by the distant whistle of locomotives pounding through the night, by the caravans leaving on the Golden Road to Samarkand, by quinqueremes of Nineveh from distant Ophir . . . Our grandchildren will likewise have their inspiration—among the equatorial stars. They will be able to look up at the night sky and watch the stately procession of the Ports of Earth—the strange new harbors where the ships of space make their planetfalls and their departures."

I could find lots and lots of quotes about taking risks. There are hardly any about not taking risks, which might be telling. Of course, we heard earlier about Admiral Zheng, whose armada of more than 300 ships in the early part of the 15th Century sailed from China all the way to Africa. The flagship of his armada was more than 300 feet long. Compare that to state of the art 1492 [European] naval technology. What would history have been like had the Emperor not had all the ships burned and made it a capital offense to build a ship with more than two masts? We might all be speaking Chinese now. I'm not sure. It's important, sometimes very important, to take risks, because the costs of not taking them can be greater than taking them.

I want to end on a more cheerful note. My favorite philosopher, Mark Twain, commented on more than the weather in San Francisco in the summertime. He also said "Twenty years from now you will be more disappointed by the things you didn't do than by the ones that you did do. So throw off the bowlines. Sail away from the safe harbor. Catch the trade winds in your sails. Explore. Dream. Discover." ■

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Discussion

MILES O'BRIEN: We have a little bit of time left, and I just wanted to open it up. Raise your hand if you have a question.

QUESTION: The question I have for both Jim Lovell and Jack Stuster is: It seems to me one of the key differences between the explorations which you have studied so much and space exploration is something that you touched upon, that is, the relationship between the leader on site and the team at Mission Control. That, to me, seems to be a big difference between the polar missions where the leadership of one person on the ice meant everything and space missions which, ultimately, like it or not, will be second-guessed. What is the best way, as NASA plans missions of great length, to work that out so you don't end up with a Skylab mutiny-type situation?

JAMES LOVELL: Well, let me answer that question in this manner. In the early days of our space exploration, as many of our audience knows, the people who designed the work to be done on the spacecraft, sitting back at a desk and thinking of what to do, often had an overabundance of things to do until you got into the spacecraft. When you were actually working in zero gravity and you had the ability to adapt to that zero gravity, you were overburdened with things to do at the beginning. So, the people on the ground have to realize what the conditions are in the spacecraft to be able to accomplish the tasks that you give the crew. In the early days, this was a lot of times not thought about until the crews sort of rebelled and went back to the controllers or mission planners and said, "Look. Here's what we can do, and here's how we have to stretch out the agenda."

JACK STUSTER: You're right. The early explorers, of course, had no way of communicating with their base of operations. And, even when it became possible, some didn't take advantage. For example, Shackleton could have had a [radio] transmitter on board the *Endurance*—he chose not to, because he didn't want to have that connection. And I've discussed this issue with Claude Bachelard of the French polar program, and if he had his way, he wouldn't have much communication at all with home, only the most necessary things, because of the potential for problems. In that list that I mentioned very briefly of the behavioral issues, number one is group interactions. Number two was outside communications. And most

OPENING PHOTO:
View of the flight director's console in the Mission Control Center, Houston, Texas, during the Gemini 5 flight in 1965. (NASA Image # S65-28689)

of it had a negative valence to it. So communications is definitely an issue, but NASA is doing an awful lot in that regard.

The Life Sciences folks at NASA Headquarters have sponsored a great deal of research just on this very issue of communications between on-orbit crew and Mission Control. I watch every morning NASA TV, and the relationship that Mission Control folks have with the International Space Station crew is wonderful. It just seems terrific, and it goes both ways. The crew learns how to deal with Mission Control, and Mission Control learns to be sensitive to the special issues of the crew as well.

MILES O'BRIEN: Of course, on Mars you'd have a 40-minute roundtrip for communication. That would probably complicate things a little bit. It would be more like e-mail.

QUESTION: I just recently downloaded the Saturn I user manual that the Skylab guys referred to, and it says the specification for reliability on the Saturn 1B system was only 0.88. Now, with the Shuttle and how we've gone towards the all nines or five nines (.99999), where do we look at the boundary of reliability, which you were talking about in your discussion?

JAMES LOVELL: Well, it's tough to answer that. I think a general assumption that whenever we design any component, whether it's a booster, a spacecraft, or a segment of something, we try to get the greatest reliability. We try to man-rate the system so that we can have reliability on the system that we're going to use. Now, I don't exactly know what all the percentages are of the various items that we've used over the years. But I would assume that in our present operation, and in the future work on some of the new vehicles that we'll design, that is one of the greatest concerns and greatest pushes that we will try to do, is to get the greatest reliability. And we do that again, as both of us talked about, with redundancy, and the reliability of the components themselves. And we learn a lot, by the way, by past experience. I didn't mention that, but Apollo 14 took off with a lot of things changed to it based on the potential that 13 had. They looked at all sorts of things before they launched Apollo 14, in about a nine-month cycle before they could relaunch it.

QUESTION: I think there is a critical point, that is, evaluation of risk could be approached objectively by a variety of techniques, and you can try your damnedest to reduce that. But at some point someone has to make a decision—.88 or .89, who makes the decision and on what basis do they make the decision? Is it subjective, objective, a democratic vote? How do you do that?

JAMES LOVELL: I'll answer again. The decision is made on, what is the reward? I've mentioned that critical thing on Apollo 8. The Americans thought, our NASA folks thought, that the reward during Apollo 8 was well worth the risk, whereas the Soviets thought that maybe they should send another unmanned spacecraft before risking a new cosmonaut. And, so, you had to look at the reward. If the reward is tremendous, then we have to accept a tremendous risk that is involved with it. Like any other risk factor, if you invest a lot of money in something, you have to think that that's well worth the risk to invest that money to get the reward back. And it's the same way with almost any operation that we do. That's the way I look at it.

MILES O'BRIEN: Jack, just to follow up on that, to what extent did the polar explorers get specific about the risk? Or was it just all a gut feel?

JACK STUSTER: It wasn't a mathematical exercise, that's for sure. It was highly subjective. But it is a personal equation, and some people are willing to accept more risk than others, and it all depends on what the potential benefit is. If the potential benefit is great, then we were justified in taking a greater risk.

MILES O'BRIEN: Would Shackleton and Amundsen have been good astronauts?

JACK STUSTER: I think so. They would have been good mission managers, because they attended to every detail. For them, there was very little risk, because they had already attended to every detail, unlike others who didn't. But, if you attend to every detail, if you had planned for every possible contingency that you can think of that might occur, reasonably, there's a certain confidence in your ability. It's not really taking a risk. The risk is something out of the ordinary, the weather, something that might come up that you can't really count on. And then, you compartmentalize it, and it's okay to deal with it.

MILES O'BRIEN: Any other questions out there? Yes, go ahead.

QUESTION: My question is, how do you evaluate the reward? And, just as an example, think of Cortez and Pizarro, they would have thought that their expeditions to the New World were accomplishing great benefits for Spain, but we see them as genocidal, wiping out great cultures. How can there possibly be an objective measure of reward or benefit?

JACK STUSTER: Well, I think if we encounter other living beings of some sort, or some other entity, that would be a parallel. But, if it's a matter of science, then you measure the actual importance of your discovery, and it becomes, again, a subjective thing. I think astrophysicists and astronomers might be more inclined to take greater risks than geologists to rescue the Hubble [Space Telescope]. I think it is a personal equation. Am I wrong? Well, what I mean is, if the outcome is important to the individual or to a discipline, then those people are likely to take greater risks. But no one wants to make a rash move, however motivated, however wonderful the benefit might be. He wants to make sure that everything has been covered that can be beforehand, to minimize the risk. But the very nature of exploration makes it almost impossible to predict what you will get in the way of benefit.

MILES O'BRIEN: The very nature of exploration makes it impossible to predict what you will retrieve.

QUESTION: Miles, this may be as much for you as the panelists. We have an interesting juxtaposition of risk taking this week. Burt Rutan is getting ready to fly on Wednesday morning. And he would argue that he has carefully balanced the risk/reward ratio, and he is very proud that he's never lost a test pilot. And he clearly thinks the risk is worthwhile. But NASA is often held to a different standard, because it's the government somehow making that decision, rather than an individual. Government has facilitated Rutan's flight, and has clearly said that if he wants to do that himself, he can. But how does the government take that similar risk? Does it get harder and harder to do?

MILES O'BRIEN: Yeah, is the bar set higher because you're a government entity? I think that's true. If Burt Rutan, as a private entity funded by Paul Allen, wants to do this, I think the level of acceptance that people have over the consequences of that, whatever it may be, I think it's greater. And I don't have an easy answer for how a government agency can accept that same level of risk. But, the other side of it is, you have all these smart people in this room, and a lot of resources that you can bring to bear to try to minimize that risk even more. I mean, Rutan has done what he has done so far for around 20 million dollars. And what is that? That's a NASA study, right? A few NASA studies. [Laughter] But, nevertheless, it is pennies on the dollar compared to the amount of cost and amount of resources that NASA has. So, I think that maybe that allows you to accept and create risk with more safety.

JAMES LOVELL: Let me answer that if I could, because I think the classic example was, President Kennedy got up in 1961 and, in his speech, he said we plan to land a man on the Moon and bring him back from space before the end of the decade. Now, we had just put Alan Shepard up two weeks before, in the suborbital flight, had not yet put anybody up in Earth orbit, much less thought about sending anyone to the Moon. So, he saw that this was a risk, because of the position that the country was then in, we were behind the Soviets at that time in technology, and they were doing all these things. And he had to get a position where he thought he could make a bold move. So, he, as the President, represented the government, represented the people, thought that we could do that particular job. It was a huge risk. If we failed, what would be the situation? He took it upon himself as the leader to put us in that position.

JACK STUSTER: Burt Rutan is reducing risk, it's my understanding, to win the X Prize. It is the weight equivalent of three people. There is only the one person and then the weight equivalent of two people that are going up. So, he has reduced the exposure to risk by taking the weight equivalent.

MILES O'BRIEN: I'm trying to get one of those seats.

JACK STUSTER: I know. [Laughter]

MILES O'BRIEN: And there would be no shortage of volunteers, either.

QUESTION: After the Apollo I fire, the Nation grieved. The spacecraft was fixed, and it flew in a very short period of time. After your mission, there was a similar sort of thing. There wasn't a lot of discussion. There was some, but not a lot, of asking, "Why are we doing this?" There seemed to be a compelling thing drawing us out there. Flash forward to the *Challenger*. There was a lot of hand wringing. It took a lot longer than people thought to fly again. Flash forward to *Columbia*. Although something came from this in a space policy, it still seems to be so much more difficult to get back to what seemed to be so natural in the '60s. For either of you, have we lost something since then? Is there something that can be regained? Is there a magic phrase or something you can do that can bring that back, or were we just lucky at that time?

JAMES LOVELL: Well, I think you have to look at the accidents in the context of which they occurred. With the Apollo I fire, there were problems because we did not really understand the use of sixteen pounds per square inch oxygen in ground tests, which we learned very belatedly. The program, at the time in which that fire occurred, was one of intense competition. It was intense prestige in this country. It was one that wanted to be continued to go on to completion. After the Apollo, as we all know, nationally it was sort of like a ship without a rudder for a while. We had various stages of the Space Station. We tried to figure out what to do. What I first recall is we were going to build a space station, a shuttle, and a transportation device all at one time. We found we couldn't do that. I think that a loss today, a *Challenger* or *Columbia,* as compared to a loss during an intense period, is entirely different. We watch these spaceflights take off on television with seven people involved. It is an instant tragedy when we see something like that happen. Actually, I lost more friends testing airplanes until the *Challenger* accident occurred. We took that loss. As you, Jack or Miles, mentioned, sometimes you become accustomed to certain risks. In test flying, we become accustomed to someone buying the farm occasionally, and we didn't think more about that. We try to learn what happened, and then we try to change the system and to improve the system so it won't happen again. Now there are major tragedies. If we lose something, it is a major tragedy because it represents part of our country.

MILES O'BRIEN: Jack, what was the media response after Scott's team perished? Was there a call never to go back to the Poles?

JACK STUSTER: I don't know. I'm not sure what the media response was. There was a great deal of finger pointing and probably a lot of similar response. It didn't stop the progress of exploration

MILES O'BRIEN: People weren't calling for the end of that exploration necessarily?

JACK STUSTER: No. As a matter of fact, it was ennobled. The heroic death of Scott and his polar party wasn't acknowledged. There wasn't the inquiry, let me put it that way, that resulted in the detailed list of changes that must be made for the next one.

MILES O'BRIEN: Question?

QUESTION: In putting together a team for a high risk mission, what relative emphasis should be put on, on the one hand, technical knowledge/training, and, on the other, personal qualities, like resourcefulness and the ability to control an out-of-control situation?

JACK STUSTER: Does it involve isolation and confinement? A small group? Isolated and confined? Technical performance? You will find that people who are technically competent might be called upon to perform their expertise only occasionally, whereas if they are living in isolation and confinement, they are always interacting with each other. So, the skill you should really select for under those circumstances is getting along with each other, and then ensuring that it's the case by demonstrating it, rather than as a test, by simulations or past performance. Of all the principles of the behavioral sciences, ranking them in order of validity, the best predictor of future performance is past performance. You find people who have been successful cooperators in the past, and you have a better chance that they would succeed. If you are going to go to Mars, 13 Norwegians with some seafaring experience would be good. Just don't pack the blubber lamp, right? It would be a bad thing.

If I could return to the question, the question was, what is the relationship of risk and benefit? NASA is compelled to justify the activity. Often it is the spinoffs—Teflon and so forth. There has been one that I have hoped for a long time. Long duration space exploration will result in bone demineralization. It could be the show stopper. The bones become brittle in the same manner that elderly people's bones become brittle, to the extent that it could be dangerous to the explorers, either when they make their planetfall or, certainly, when they return. There are a lot of very smart people financed by NASA who have been looking into this issue to develop a countermeasure. There are people who take the mechanical approach of stressing the bones to trick the osteoblasts and osteoclasts into leaving the bones alone, and so forth. I have been hopeful that a solution would come. I have just learned that if this pans out, it will be the most monumental spinoff that NASA has ever come up with, and, certainly, will justify all previous research and all future expeditions and research, and that is a countermeasure in the form of a pill to bone demineralization. Everyone has an elderly relative, a grandmother, a mother, who fell and broke her hip and either succumbed as a consequence or the quality of her life was changed. All of us look forward to a future where we will live in fear of falling and breaking a hip. This countermeasure successfully developed by NASA will change all of that and would be, as I said, worth all of the effort that went before and will occur in the future.

MILES O'BRIEN: Sounds like a story to me. [Laughter]

JAMES LOVELL: Jack, you're not suggesting we send John Glenn up again, are you? [Laughter]

MILES O'BRIEN: Okay. That's all the time we have. Great panel.

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