NASA Symposium: Risk and Exploration

9.27.04, 10 am - 12.30 pm - James Lovell, Jack Stuster

Miles O'Brien: I don't think Jim Lovell needs much of an introduction. Everybody knows him. You know who he is. He's a great man who endured one of the great adventures in space ever and we look forward to hearing his comments. Give him a warm round of applause.

Jim Lovell: Thanks, Miles. Thank you for that very kind and very short introduction. First of all it's really a pleasure for me to be among my old contemporaries. I'm an old, 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 that the previous speakers and Miles have really set the scene for this discussion of how we perceive risk. Now, I kind of would like to expand this concept of risk as it pertains to space flight 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.

Now, the first story takes place long before we had NASA astronauts. After World War II, Werner 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 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 -- Gemini 7, Frank Borman and I 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 sort of way overblown. Now, 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 one of the first couple of missions -- three and a half hours or even one day [in length] - 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 and everything but the 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 see and as I do 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.

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 eleven 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 -- 0.99 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 in-flight 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 added 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, etc..

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 kind of 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 there was an injector line on the surface that 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, I guess. 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 space flight.

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.

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 of 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. 'Round', 'square'. (laughter)

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 also there was another little incident of course 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? Apollos 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 all in-flight 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 once 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 to the moon, our research shows be sure you have it 200,000 miles out. (laughter)

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 mindset 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, he 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”.

I brought with me -- a lot of you probably saw it, but I thought I'd show it just in terms of risk -- a short video that we made for Congress in 1970. You know, they investigate everything, and this is one of the investigations. If I could have that now - it's silent. I will narrate it for you.

We call it a “Quick Look”. We hadn’t yet figured out what exactly caused the accident, but they wanted to get information as soon as they could. There is our Saturn V. My own personal opinion is that we made a big mistake to not keep building the Saturn V. It could put more mass into low earth orbit. A perfect vehicle for the International Space Station. That's my own opinion, though.

[Laughter]

[Applause]

So three people . . . There's our crew getting suited up. Now, notice as we get suited up -- In fact, Swigert is still trying to figure out how he got on the flight.

[Laughter]

But notice that we are completely suited up. We are breathing pure oxygen to purge our bodies of nitrogen because in those days we designed and flew the spacecraft at low pressures: five-and-one-half pounds per square inch. We didn't want to get the bends. We learned something from the Russians, and sometimes we learned things otherwise.

[Recall those] Shuttle crews coming out of the building into the van. They're not wearing helmets. They're not breathing pure oxygen. Why? Because we now fly the spacecraft at sea level pressures. Something we learned.

Going down to that vehicle, of course on launch date, is of course, really a thrill because it's still that five-and-a-half million pounds of high explosive. Only a couple of nervous check-up people are there as they get the crew in. But we have all the faith in the world in them now.

Of course, here's the Launch Control Center. In those days, we didn't have the sophisticated computer technology we have today. We had mainframe computer technology. You won't see any laptops there. You won't see any CDs or floppy disks. These people used the computer. In fact, I think the last part of the countdown was completely computer-controlled. Of course, I'm talking from ancient history now. I don't know what you all do, which is probably a lot better than we did.

But the last six minutes, I think, we're computer controlled, and then the last few seconds we lift off. This concept of all liquids is something I think has been talked about, back and forth, whether it's liquids and solids are good as far as the risk goes, the type of spacecraft, but this was an all-liquid engine and we used five. It's kind of interesting, because when the Russians built the N-1, they had, I think, thirty-six engines at the base and one of them was bound to fail sometime. But we just had the five. So that was the way that this was designed by the Marshall people. And notice that we had an escape rocket at the top -- we had a way of getting off. And, of course, I think we were using--our thrust, now, was about the same as the shuttle, about seven and a half million pounds of thrust as we went faster as we went up.

We had, of course, abort modes after--if something happened to the booster after a certain time. After a certain time we couldn't use the escape rocket any more, and then we had other abort modes where we could get back in and make returns. It took us about a minute and a half because of the loss of the second stage to get into Earth orbit which we did -- again, we did to test out the vehicles prior to sending them to the Moon. So there was an extra safety factor. If something went wrong with the vehicles in Earth orbit then, of course, we would not light our third stage a second time to go all the way to the Moon. Now, you're on your way to the Moon, here, and here is the situation. And another factor, the crew, as you know, we replaced Ken Mattingly--here's TK [Mattingly] out here in the audience, with Jack Swigert --you can imagine his emotions. Highly disappointed to be kicked off the flight. Secretly elated when the explosion occurred.

[laughter]

So with only four days training and because Jack was well-organized anyway, we had no qualms about replacing a crew member to have Jack on board. You see him now trying to dock the vehicle. And you take a look at this Lunar Module --we talk about construction and reliability--look at the skin around the [drone], because we have to put a probe into that [drone]. And Jack can't see the probe, so we used a gun sight and a target that you see there to drive the two vehicles together. We had to do a transposition in docking. We had to disengage from our third stage. We had to go around and come back again to dock. All these were intricacies that are going to have to be relearned again when we go to the Moon again. I'm sure there are some systems that are going to be there.

That's the third stage, of course, that follows us to the Moon. Ground has taken control of it. We still had the ability to have one experiment go on this flight that was successful. They crashed that third stage into the lunar surface and found out a lot about the surface.

Now, here's this complacency that was talked about earlier: Take a look at the controllers as the camera swings around. No one else, of course, saw this on TV. The fellow on the left, I think he's just about asleep. [laughter] Now, finally, I got to work. We've got a lot of work down here and no-one carried the program anyway. And then, of course, right after that the explosion occurred. Now here's the crisis mode. Now here's the dead Command Module. And it died quite rapidly. The only light we had was coming in from the sun. This was taken by Fred with a wide-angle lens on a movie camera, but as the camera swings around, we had already opened up the Lunar Module , trying to see if we could use it. Here's the hatch that normally would close the tunnel between the two vehicles. Fred will now take you into that Lunar Module where Jack and I were trying to figure out how to get home.

This Lunar Module is so fragile that--and Swigert had never done any work in Lunar Module s and we were afraid that he would stretch out his feet and bend the door that was down below--so we had to caution him all the time about moving around in the Lunar Module .

We had a little bit more room here and here's where the teamwork started to come in, between the ground and the crew trying to figure out how to get back home. They called all the contractors to see if they had any ideas. Procedures that normally took weeks to develop and weeks to test to make sure they're OK. Now they had to be done in hours and they had to be right the first time. You had to have good teamwork to go. You had to figure out what the crises were. They even called in a lot of good people and they even called in TK, and to tell you the truth, he was bumped off because he thought he was going to get the measles and he never got the measles, of course.

One thing that we had that we didn't realize: The way we normally controlled the temperature in the spacecraft in those days was to balance the heat blown off from the electrical equipment and the heat that was radiated out into space as we used radiators. But with all the electrical equipment turned off, we were radiating heat out into space more than we were gathering it in from the sun, and consequently, all through the flight, the temperature kept dropping and dropping until it got to about thirty-eight or thirty-four degrees Fahrenheit at the end of the system.

Again, the three of us working together, we came around. And here's where innovation or imagination took place. How do we get out of the CO2 crisis of being poisoned by our own exhalations? And, of course, here's what the crew system division did, using the tape, plastic, and cardboard to jury rig a system that worked in the Lunar Module system. Of course, any time you're in a crisis, any time there's a problem, you start to get tired. You have to keep organized, you have to keep thinking positive. People often ask: "did the crew get to be pessimistic?" And the answer was: "no, as long as we had something to do to keep going in this crisis, we felt optimistic about the whole operation."

One of the things that we tried to do, because of the temperature dropping, was to barbecue the spacecraft perpendicular to the sun. And here's what we're trying to do right now, rotating it perpendicular to the sun to try to get heat into the spacecraft. Not successful. But there's the Earth going by at 110,000 miles out. If you want to know how insignificant we really all are, you just hold your thumb up and you can hide everything that you've ever known.

And finally, I had the duty of -- there's Jack trying to get some sleep -- we got very little sleep. The temperature kept dropping. The Command Module was completely frozen. All the food was frozen. But on the other side, notice that Fred keeps his hand in his blouse. We learned something from a previous flight. Pete Conrad, a great guy, was flying in a completely enclosed, darkened Gemini spacecraft, trying to get some sleep, woke up, saw this strange eye staring into his face. Scared him half to death! Thought he finally saw one of those UFOs he kept hearing about all this time! Turned out that his arm had drifted up and he was looking at the luminous dial on his wristwatch.

[laughter]

Now we keep our fingers clear. One of the things we learned in those days. Now they have more sophisticated devices on spacecraft, I'm sure. Again, every little thing might count. So how do prevent the spacecraft from getting off the proper trajectory? Don't jettison anything over the side. There's three nervous guys trying to figure out where to store urine for four days. [laughter] And finally, that seat-of-the-pants maneuver coming back down again. The procedure had been designed for Apollo 8 and we knew that--we took the procedures out of the books after Apollo 8, thinking they were never necessary.

There is the service module going by. Normally, we jettison before we hit the atmosphere. We did that, and as it tumbled on by, we saw that the entire side had been blown off, and of course the ground was worried and we were worried too, but nobody said anything to each other. If that explosion had damaged the heat shield right behind us, that's all it would have been. And therefore, we have to have confidence in our equipment. The parachutes. We couldn't afford the pyrotechnics to keep them warm to put out those parachutes. They were cold-soaked for four days. If they didn't go out, of course, we would all have seen this spacecraft hit the water a little bit faster than you're seeing here. So we were very successful in this particular flight due to a lot of very good people working hard and looking at some of the risk-reward factors.

And, of course, everybody's happy back at the space center back in Mission Control. I think they very quietly tore up the obituaries they had all planned for us. The helicopters came over to drop a flotation device--again, another safety factor. Before we open up that hatch, let's get a safety flotation device around it so we won't sink the spacecraft. We did that.

You might be all familiar with this helicopter. It was number sixty-six and it picked up about four or five other crews. When Ron Howard did the movie, by the way, the Navy didn't have these helicopters any longer. He found a civilian model and had it repainted with Navy "66" on it for the final sequences of the movie. And we were also very fortunate, in the last part, to have an uplink on the carrier to talk to a satellite allowed TV coverage for this particular flight. We went over to thank the captain for being in the proper position. Of all the places we could have landed--the Atlantic, the Pacific, the Indian Ocean--we landed exactly where we would have landed, except we got there a few days early. The chaplain was very kind; he gave a prayer, millions of people prayed for our safe return. So fifty-five countries offered water recovery assistance for us. Even countries like Paraguay and Czechoslovakia. They don't even have coastlines! I don't know how they were going to do it.

[Laughter]

And finally, after every successful mission we were able to talk, I think, to the President just briefly, and then to our wives. I forgot to mention Jack Swigert was also a bachelor like T.K. Mattingly, talking to every single stewardess on Eastern Airlines.

[Laughter]

Thank you very much.

[Applause]

Miles O'Brien: Amazing story. Doesn't matter how many times you hear it, it's an amazing story. If you're going to go to Mars, you better like the people you're going with. And I think we can all name some people we'd like not to go to Mars with. And the question is, how do you decide? And how do you figure out ways to make people get along in close quarters for long periods of time without cable? How do they do it? Dr. Jack Stuster has spent a lot of time doing just that. His book, "Bold Endeavors: Lessons from Polar and Space Exploration", I suspect, is on many of your bookshelves. Please welcome him.

[Applause]

Jack Stuster: Well, 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 way we take the risk of driving on the highways, where presently 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 three or 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 and individuals explore sometimes to satisfy a need for achievement, to do something special, 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. 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 two interrupted his voyage, he might not have taken that risk. He did maintain two journals, one for his own use, and then one for the crew, that showed that they were making far greater progress than they actually were -- a way for him to minimize his personal risk on board.

[Laughter]

There are many justifications for exploration. One of my favorites is from Fritjof Nansen in a Norwegian explorer that might seem appropriate in this age when people complain about spending money on space. I mean -- we should spend it here -- as if the money were actually taken into space and thrown out of the spacecraft. But Nansen wrote -- who was a scientist as well as an explorer -- 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 one of the first supporters of women's suffrage, so please don't judge him by his 19th century usage of that term ('man').

Roald Amudsen 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 Amudsen 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 Amudsen 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 that in the storm. It had been an unusually stormy -- 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.

Ashley Terry Gerard, 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. They used Manchurian ponies, which didn't really cut it in the snow, nor had they ever tested the tractors they took to Antarctica with them in snow. There was a certain hubris involved. Amudsen 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 been -- forgive me, Michael ["I ski now" Michael Foale replied from the audience.] -- it might come in handy -- most of my work has involved the risks associated with the psychological aspects, the behavioral, the human aspects of isolation and confinement. And I use this 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, year and a half, 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 that 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 or access to the fax 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 Wanimi, 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. And it is just a natural phenomenon that occurs. If you're prepared for it then you can somehow in that way reduce the risk.

Anyway, an expedition to Mars would be a lot like this metaphor that I've described for you. I decided to include the words of Valery Ryumin from having completed a Soviet space expedition and wrote eloquently about the kinds of things that might occur in an isolated and confined condition. 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 things such as offshore oil platforms, commercial research vessels, fishing vessels, fleet ballistic missiles, submarines, saturation divers, and so forth, and came up with 100 or so design recommendations. Its my understanding that a couple of them actually made it to the final design of the International Space Station, for which I'm grateful. And 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 big ones.

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 things -- and it came 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 reports, the lessons-learned reports, from Skylab?

So I wrote a letter to the editor and I probably angered a whole lot of people in so doing 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, Canzone, 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. And it went ashore and broke up. 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, Canzone 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 or --? And then Canzone shows up. And 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% of what you expect it to withstand; graceful degradation so that you have time to do something about it; and maintainability. Maintainability is something that when you have a human crew you should really take advantage of the crew for maintainability.

I'll move on. One of my favorite explorers is the French explorer, Jules Sebastien Cesar 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. And he saw it and wanted it for France and they dragged it down to the ship, breaking off two arms in the process. And 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, who he rarely saw. He also named the linguistic groups of the Pacific with the same names that we use today -- Polynesian, Melanesian, Micronesian, and so forth. 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 and so forth. But he was a realistic man.

On his second expedition he as 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. And at first he really objected to it quite a bit 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 really led to the demise of some expeditions -- contributed to it, at least. So the French would take bright Naval officers and train them to be botanists or natural philosophers -- I guess it was called at the time -- and artists. This rendering of the astrolabe in Antarctica was painted by a young lieutenant member of the crew.

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 "core of discovery" - a brilliant thing to do. I was very pleased in 1999 when I visited the Johnson Space Center in the astronaut office and saw a sign that said

"Expedition Core." And I asked, "What is this?" Andy Thomas said, "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 mindset 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. No? Take credit for it, Michael. [Laughter – 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 mindset 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. It 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 a good idea to find out what exactly they were doing on this 27th of September 1804 -- 200 years ago today. And 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 further 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 -- the keel boat had lost its anchor and was having trouble maintaining its position. The little boat came out and parted the remaining part of the 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 and he called all 200 or so 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, really, loaded with shot trained on the main body of the group. They had a technological edge here. They would have wiped out 40 -- 60 maybe -- 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 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. The standoff went on for a while. What Clark didn't realize was his people obeyed him because it was a military organization. The Teton Sioux were only recently a tribal organization. It was 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, that it would be resolved peacefully. And the risk paid off. Finally, Black Buffalo pulled on the arm of one of the guys and apparently told him to back away and the voyage -- the core of discovery was then 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," -- this was for the night -- "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." Ah, I'm supposed to show this to illustrate approximately where -- 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. In many studies previously, it's been 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 core 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 wouldn't -- 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, he 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 after 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. Norwegians, Romanians, 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 hidden down below where he could hide and sleep because he thought people were going to kill him. Roald Amundsen served his apprenticeship as an explorer as a mate on the Belgica and later he wrote that "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. And 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 take it each day and take a turn doing this. Whether it had some effect on them or maybe it was the placebo effect, it did have the effect of helping the crew get through this very difficult period. He also thought that exercise would help and so he required the people to take a walk 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 this 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.

This is one of my favorite pictures: Frederick Cook before the expedition and afterwards. The after picture I like because it looks like one of my roommates from my college days. The Austral-Asian-Antarctic Expedition Douglas Mawson -- I formerly neglected the Australian contribution to exploration until my dear friend Desmond Lug showed me that it was just a characteristic American narrow-mindedness to focus on these things and disregard the rest and 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.

[slide] This is not another hurricane approaching Florida. This is a dust storm on the planet Mars. They can envelope the entire planet and tell me that wouldn't affect an expedition. Roald Amundsen, the most successful of all explorers, 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 tools, wooden spoons mostly a landing strip, 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 - - but that's another story and I guess I don't have time.

I work in the field of human factors and I'm grateful to Roald Amundsen for providing this wonderful quote from the past that the human factor is three-quarters of any expedition. And you can see from his portrait there that the tradition of posing in operational garb did not begin with NASA it is a continuation of the exploration tradition.

Ernest Shackleton is probably the best known of all the explorers. Movies about him, books about him, his leadership styles, seminars at corporations to impart the style of leadership that he had developed and was so successful with. This was a picture of his recruiting ad from a London newspaper. If you can't read it I will. "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.

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 or something then the person might be okay.

I guess I don't have the time to talk about this as much as I had thought so I will just say that although Shackleton never made it to any of his destinations, he never lost a man. And on the British trans-Antarctic expedition where the Endurance was locked in the ice and they spent months on board and then several months in a camp right next to the ship and as it was sinking. Watched it sink. Moved to another camp. Then they moved to a camp that was on an ice floe that was as far 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. When it was about 100 yards across and they were all in there - - By the way, 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 rescues one of his crewmembers from the ocean, pulls him ashore and they depart. Then they spend another couple of weeks in these open boats before they made it to this tiny rock in the worst sailing conditions probably on the planet called Elephant Island where they made it ashore.

Shackleton knew that they could not survive there very long, so he selected a few other men to accompany him on the most arduous and dangerous open boat voyage probably ever undertaken to get to a whaling station, the Stromness 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 people with him of the five 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 got to Elephant Island with a borrowed tug from the country of Chile. And it's a wonderful story.

Probably the kindest thing that could be said about an explorer was said by Apsley Cherry-Garrard , who was devoted to Scott. But he wrote in eloquence about the comparison. It's a natural thing for people to compare other people, and in this case, I think it's very eloquent.

I want to talk just for a moment about Richard Byrd, because, A, he's American, and one of the few of the American polar explorers that I consider relevant. What you see on the far right is a portrait of Byrd at advance base, this little hut that was transported 100 miles from Little America, buried in the snow. And it was going to be an experiment in isolation, in confinement. And originally he was going to have two people, but wrote in afterwards 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 greatly 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 - poor human factors, 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 to slurred speech, and 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". So. His manners left him, I think, which is something that happens in isolation and confinement. It's well documented, except on NASA and Russian isolation confinements.

Norwegian polar expeditions are one of my favorites, and one I think we can derive the most benefit from. Fritjof Nansen was, well you can see here [slide] he would have had a wonderful career, in this case 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. But he was responsible for popularizing that.

Anyway, he had an idea. It's hard for us to really appreciate what the world was like at the closing of the 19th century. We take for granted communications network and travel abilities, that would 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 one of them, the most compelling, was, what's 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.

He had a plan -- well, I can't tell you the details of why this happened -- but 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 just carry you across the top of the world. So 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 he received a grant. He had to go back, not unlike modern expeditions, because of cost overruns, building in a margin of safety that he hadn't anticipated.

At a day when crews were separated – with the men who slept before the mast in the focsle , and the officers and scientists, he designed the Fram so that all staterooms opened onto the salon, or the main area, perhaps characteristically egalitarian Norwegian approach. It was a very stratified society, but he did this. He tested everything beforehand. There were spinoffs from his expedition. People still use the Nansen Cooker, people who travel in the north or in the Antarctic. It gets the last calorie of energy out of your fuel.

But the model of the Norwegian polar expedition is a really good one. You see the departure of the Fram from Bergen in 1893, en route, locked in the ice. He went up the coast of Norway, across Siberia, and at a point closer to Alaska than Norway, headed into the pack ice on purpose. Indeed, the ship was built with a rounded bottom, and no keel, 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. The theory was proved, and indeed, when it seemed like they would get no farther north, he selected one man, Hjalmar Johansen, to accompany him on a dash to the pole to see how close they can get.

After many weeks they found that they were only making a mile a day or so. 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 a Franz Josef Land where they were hit by an early winter, and here's some of the research being conducted by the Fram. [slide] You'll notice the windmill. He had a windmill installed to generate electricity for the crew, so they would have lights in the winter. And this was at a time when electricity was still kind of a novelty.

He knew that the secret was to keep people busy with meaningful work, and, of course, to be especially careful about the food. The Norwegians are not afraid of the cold. They don't talk about bad weather, only bad clothing. And he also knew that it was a good thing to keep people entertained. And among Nansen's many talents, he was an artist. And the woodcut that you see on the right, the engraving, was one of Nansen's, showing life on board the Fram.

The illustration on the left is a Norwegian 15th of May celebration out on the ice. They looked for everything they could to celebrate. After awhile they actually went into their almanac to find other countries' holidays to celebrate. Because it broke up the monotony of the day, and helped motivate them and keep them going.

On the left is a photo of the hut that they built, 6 X 10 foot 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 -- nothing to do. They slept sometimes as many as 20 hours out of the 24, in the same sleeping bags, because it was the most efficient way to conserve the heat. But they never resorted at all at any time during their nine months to any sort of conflict or harsh words. Which was the first thing that the press asked them, by the way, when they got back. How did you survive?

I don't have the time to tell you the details of how they then 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 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 . [Laughter] and Turkish baths.

When Nansen returned -- Nansen came across 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. When they got back, the day that they stepped foot onto Tromso, on Norwegian soil, the Fram broke loose from the Arctic path on the other side of the world and made its way back. They then sailed together around Norway and up into Christiana fjord, 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, founder of Norway was instrumental in the League of Nations. He also received the Nobel Peace Prize for saving hundreds of thousands of lives from the Armenian situation that occurred 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 he noticed that there was a famine underway and mounted a relief mission. Presently there are people in Eastern Europe, what used to be Yugoslavia, 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. There are main themes from my research.

Certain things are highly predictable, but they can mitigated by taking the proper precautions. One of the most important shouldn't encourage the designers to be Spartan about things: humans can endure almost anything. As I said, 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 thing? 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? Well, we don't know. I used this method to quantify. It’s based on the assumption that the more somebody writes about a topic, the more important it is. I found that group interaction received almost twice the number of category assignments as any other category, and this is the first rank ordering of behavioral issues based on quantitative data. I found, in effect, in the third quarter of the depression, and that goes whether it is a 3-month mission or a 13-month mission, about the third quarter there is a drop in affect. I thought, Isn't that a wonderful finding. This is wonderful for isolation and confinement. Then I started to realize it applies to everything. Think of your semester in college. Boy, you're only three-fourths of the way done. There's all that work yet to do, and I've only got three weeks. I think it applies.

[Laughter]

Anyway, 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. You 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 confronted by future explorers will be the same problems that were confronted in the past. It won't be the out gassing from a 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. I am wrapping up now. [Slide of Martian craters] I love the "Happy Face" crater, don't you, and, of course, this structure, this geological formation on the right is just too good to be true. It is true, though, and there is much waiting for future explorers.

One of my favorite quotes is from Arthur C. Clarke, who is one of the most prescient people on the planet, and he invented the PDA for 2001. 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 in my part of the country I am out on my roof watching it. "This progression of the ports of Earth where future ships will make their planet falls and departures."

I was going to talk -- I don't have time, I guess, about what happens if you don't do something. I look for quotes. As you can see, I like to rely on the wisdom and stand on the shoulders of other people on these things. I looked for quotes about taking risks. 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 sailing from China all the way to Africa, India and so forth. As you can see, 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 had something to say about not only the weather in San Francisco in the summertime, but “Twenty years from now you’re more likely to be disappointed by the things you didn't do than by the ones that you did. So throw off the bow lines. Sail away from the safe harbor. Catch the trade winds in your sails, and explore, dream, and discover.

Thank you very much.

[Applause]

Miles O’Brien: Welcome to my world -- getting those wrap cues all the time, except they're screaming in your ear. I think we're going to take some questions. We have a little bit of time left, and I just wanted to open it up. Is there a microphone out there somewhere? Okay. Raise your hand if you have a question. We'll get a microphone to you.

Question: The question I have for both of you, and I guess we'll start with you, Jack, is: It seems to me one of the key differences between the explorations which you have studied so much and space explorations is something that you touched upon. You also touched upon this, Captain Lovell. That is the relationship between the leader onsite and the team 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 -- 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 showed very briefly of the behavioral issues, number one, group interactions. Number two was outside communications. And most of it was negatively -- 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 Division -- they call it something else now -- but the Life Sciences folks at 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 10: 00 to 11: 00 Central Time, I watch it at 8: 00 o’clock in the morning on streaming video while I’m doing other things, 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 email. All right, question?

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, 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 what we call man-rate the system so that we can have reliability on the system that we're going to use. Now I don't exactly 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 like 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 we had, the Apollo 13 got back safely, 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 damndest to reduce that. But at some point someone has to make a decision. Point eight eight, point eight nine, once accessible, 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 mean and 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 we should send another unmanned spacecraft before we risk 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 was 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 Amudsen 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. It would help if you could stand up, please?

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 do you, how can there possibly be an objective measure of reward or benefit? Thank you.

Jack Stuster: Well, I think if we encounter ideally parallel to that would be if there were other living beings of some sort, or some other entity that would be influenced. But if it's a matter of science, then you measure the actual importance of your discovery, and it becomes again a subjective thing. Rescuing the Hubble would be much more -- I think astrophysicists and astronomers might be more inclined to take greater risks than geologists. I think it is a personal equation.

[laughter]

Am I wrong? Well, what I mean is, if it's important to you, if this is something that is important to you, 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 retrieve, what you will get in the way of -- yes.

Miles O'Brien But 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 is carefully balanced the risk/reward ration and he is very proud that he's never lost a test pilot. And 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 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. 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 the government, a government agency, can accept that same level of risk. But the other side of it is, until 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 ever more. I mean he has done what he has done so far for around twenty 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 Shepherd up two weeks before, in the suborbital flight, had not yet put anybody up in Earth orbit, much less think 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 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]

Question: And there would be no shortage of volunteers, either. Anybody else? Over there? Yes?

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. 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. The Apollo I fire -- and 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 that 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 a 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, as Challenger or Columbia, as compared to a loss during an intense period, is entirely different. We watch these space flights 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 that 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 insuring 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 this -- to justify the activity. Often it is the spin-offs: 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 planet fall 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 spin-off 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 their hip and either succumbed as a consequence or the quality of their 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. Give them a round of applause. They were great.

[Applause]