SESSION TWO

sea

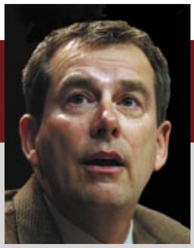
NASA Image/Renee Bouchard

Diving Shipwrecks

I have a fantastic job working for the History Channel. I travel around the world, I get to talk to some very interesting people, I get to talk about history, and I get to dive shipwrecks. This winter, I think I am going to be in France, Scotland, Croatia, the Dominican Republic, and the South Pacific. And when I'm not addressing an audience full of astronauts, I say I have the best job in the world.

Prior to my working for television, I spent more than 20 years working as a commercial diver, largely in and around New York City, where I worked on everything from nuclear reactors to bridges to pipelines—wherever the work was. That was my day job. Before I even got involved in commercial diving, I was diving shipwrecks for recreation. I was attracted by the history, and I was attracted by the challenge that wreck diving afforded me.

There is a big difference between commercial diving and scuba diving. In commercial diving, the diver is a cog in the machine. He is part of a bigger team. When it comes to scuba diving, you are everything. You are your own dive planner and your own dive support. You are your own dive rescue. There is a certain freedom, and, of course, that's linked with responsibility. Eventually, as I acquired more and more experience, I started diving deeper and



John Chatterton
Professional Diver

John Chatterton spent more than twenty years working as a commercial diver and as a boat captain. His passion, however, has been researching and diving shipwrecks. In 1991, his discovery, and then subsequent identification of the German submarine *U-869*, in 230 feet of salt water (fsw) off the coast of New Jersey has been the subject of several television documentaries and now a bestselling book by Robert Kurson, *Shadow Divers*. His diving credits include more than 150 dives to the passenger liner *Andrea Doria* (250 fsw), the first trimix-breathing expedition to the *RMS Lusitania* in Ireland (300 fsw), and the first rebreather dive to the *HMHS Britannic* in Greece (400 fsw). John has worked on numerous projects for television and is currently hosting the television series, *Deep Sea Detectives*, on the History Channel.

OPENING PHOTO:
Inside the Aquarius research habitat, a curious astronaut, Clayton C. Anderson, smiles as he is greeted by an equally curious school of marine fish peering through the habitat viewing port in waters off the Florida Keys.
(NASA Image # JSC-2003-E-45587)

more challenging wrecks. I found myself going deep inside wrecks like the *Andrea Doria*. The goal of these dives was just to go where other men had not yet been.

In 1991, Captain Bill Nagle got a set of coordinates from a fisherman 60 miles off the New Jersey coast in what we were told was about 200 feet of water. We put together a trip to the site, we went out there, and what we found was a wreck in 230 feet of water. It was a submarine, later identified as the German U-boat *U-869*. It was a submarine that no one was aware of, where it was, or that it existed. No government, no navy, no historian, no expert could tell us which submarine this was. What an irresistible mystery. It afforded the divers who discovered it the opportunity to rewrite a page of history. We thought at the time that it was going to be a matter of a day or two—on the next dive we would be identifying this submarine. Of course, that didn't happen. It took six years to positively identify it.

In retrospect, looking at our plan, we broke it down into three divisions: economics, operations, and psychology. Economically, we had no financial assistance. We had no support. We had no budget. Essentially, I was going to have to do it on my lunch money. That meant that we were going to dive the wreck to try and identify it the way we had been diving it—as scuba divers. It's a minimalist approach, and it is extremely risky. It's dangerous. Operationally, what was our plan? Well, there were certain legalities that needed to be addressed, dealing with the German government. We then had to do research. Of course, research is what fueled our dive plan. What was there on the wreck site that we could recover that would positively identify the wreck?

The teamwork that we used was indirect. In other words, we would work with one another on research, we would work with one another on planning and coordinating, and that kind of thing. However, you can see that in an environment like this one, to put two or three divers in there is counterproductive to making the dive safer. Because of the silt, because of the very tight spaces in there, and because of the entanglements, you couldn't get in there with more than one person at a time. Specifically, the risks that we were facing relative to the diving were decompression sickness, the possibility of oxygen toxicity, and equipment malfunctions or failures. When we started diving the wreck, we were diving it on air, and we quickly converted to tri-mix with nitrox and oxygen decompression. We had to use redundant systems for primary systems. We also had to be very conscious of health problems. If you faint out in front of this building, they are going to call an ambulance, and they are going to come and get you and take you over to the hospital. If you have a medical problem deep on a wreck, you're going to have a difficult time surviving.

On the wreck itself, it's dark. There are entanglements everywhere. You can see there are hanging wires and that sort of thing. There are fishing nets. There is also the possibility of entrapment, of a loose piece of wreckage collapsing onto the diver. That happened to at least two divers, me being one of them. I'm the only one that survived. You can get lost, either inside the wreck or outside the wreck.

And, then, there's the possibility of panic. The thing that panic does in a very stressful situation is, all of a sudden, your decisions and your actions are not logical. They are not in your own best interest. My goal in this dive was to find a small pad on those hatches at 12 o'clock, which we knew existed. The problem was [that] it was made from white metal that completely [had] corroded away.

Psychologically, this is an extremely intimidating environment. Aside from the fact that 58 German sailors lost their lives inside this submarine, a total of three divers lost their lives diving the wreck while I was working there.

So, you have changing conditions. You are diving by yourself. You also have to consider how obsessed you are, how driven you are. Is this affecting your good judgment? We talked about this yesterday on the panel: when do you abort the mission? You have to be able to do that while you still can.

Six years later, I brought out a tag that positively identified the wreck as U-869. The CBS program NOVA did a two-hour documentary on it. The people that I worked with on that documentary later introduced me to the History Channel where I now work. Robert Kurson saw the documentary and wrote the book *Shadow Divers: The True Adventure of Two Americans Who Risked Everything to Solve One of the Last Mysteries of World War II*. Now Twentieth Century Fox has

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bought the rights to the book, and Bill Boyles, the man who wrote the screenplay for Apollo 13, is working on the screenplay as we speak.

Why go through all this? My ex-wife used to ask me that all the time. And I didn't have a snappy answer like George Mallory. It has to do with challenge. It has to do with perseverance. It has to do with who we are, not just as individuals, but, really, as a culture. Exploration is very much who we are, and we really have two choices. We either continue on a path of exploration, or we just quit. Not everybody is comfortable with quitting. Certainly explorers aren't. As an added benefit, I am going to close with this letter. I get letters like this occasionally. This one came last Friday.

"My name is Anka Hartung. My grandfather was Mr. Eric Poltey. He was the machinist [obergefreiter] on the submarine *U-boat 869*. As fate might have it, my family and I saw by chance your film about the submarine *U-869*. We are totally moved that we now finally know where our grandfather lies. You and your team have done an awful lot for the families of the lost men. Three people died and you yourself have often risked your life in order to bring certainty and peace into our lives. My grandmother is unfortunately no longer alive to share these feelings with us. You and your team have done so very much for Eric Poltey's relatives, and we sincerely thank you from the bottom of our hearts."

NASA Image/Renee Bouchard

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Deep Ocean Exploration

Thanks to all you explorers out there for coming to talk about the wet part of the universe. This conference, of course, is dedicated to the concept of risk. And maybe there's an underlying message about why expose real live human beings to certain obvious dangers when you could—and maybe should—send a machine? Well, I love machines. I mean, I have had a hand in building quite a lot of them, developing and using hundreds of variations on the theme of little machines that operate remotely, as well as those that take a few real, live people inside. And when a job is right, I do believe that it's obvious—you know, pick up a robot, send it, and enjoy it, such as when you're exploring deep under the ice in the Antarctic or in the high Arctic. Send a robot first to check out what's down there, before you go look for yourself up close and personal. I whole-heartedly endorse the concept of using whatever tool does the job, but I think I share with maybe everybody in this room the belief that there's nothing like being there, right? If you can actually get there, why not?

But what about the risk? I'm asked about that quite a lot. You know, why do you do the things that you do? Aren't you scared? Aren't you concerned? I mean, you have a family; don't

Sylvia Earle
Founder and Chair, Deep Ocean Exploration and Research, Inc.

Sylvia Earle is an oceanographer, marine botanist, ecologist, and writer. A pioneering aquanaut and marine explorer, Earle made her first scuba dive at age 17. She has since set the women's depth record for solo diving (1,000 meters/3,281 feet) and logged more than 6,000 diving hours—feats that garnered her the moniker "Her Deepness." The author of five books and numerous scientific and popular articles, Earle tirelessly calls for the preservation and exploration of the world's marine ecosystems.

OPENING PHOTO:
Dr. Sylvia Earle prepares to dive in a JIM suit. (Image ID: nur07563, OAR/National Undersea Research Program (NURP))

they object to the idea of you going down underwater? It's dangerous! My answer is usually the same. The most dangerous thing I do almost every day of my life is to get into an automobile, get on the highway, and move along at reasonably moderate speed, and I face traffic coming the other direction, and the only thing that keeps me from banging into that traffic is a painted line down the middle of the road and a mutual desire—I hope it's mutual—to live. That's really dangerous.

I think about explorers of the past and what they would think of this conference. I mean, we are so obsessed with safety these days, so obsessed with risk. Can you imagine what OSHA would say about Christopher Columbus, or about the *Challenger* [oceanographic] expedition in 1872 as they made their preparations to go for four years around the world, going places where nobody had been, exploring deep parts of the ocean? Imagine what they would say about William Beebe with his little bathysphere and Otis Barton, the engineer [who created the bathysphere]. And if you've seen any of the films—and I have—of their operations, anybody associated with OSHA would have heart attacks just watching. No hardhats! No hard shoes, running around barefoot on the deck with this heavy equipment being slung around. Who would have insured Beebe or his machine back in the 1930s? There's something that's happening to us as a species as we become risk-averse.

But I share with Anne Morrow Lindbergh some thoughts about risk. She and her husband Charles paved the way for the first flights across the North Pole, looking for ways to establish new commercial air flight routes back in the 1930s. And when asked by a reporter as they set off for their first flight across the North Pole—north to the Orient—the reporter asked her, "Can't you even say that you think it's an especially dangerous trip?" And she said, "I'm sorry, I really don't have anything to say. After all, we want to go. What more is there to say?" And that's it. You know, as explorers, like little kids, we want to know what's around the next corner, what's under the next rock, what's over the next horizon, what's in the deep, what's beyond the next star—or starfish.

Danger is the silent partner of exploration, no doubt about it. But just try to avoid risk in everything you do. I have a home in Florida—that's risky! I have a home here in California—think of the earthquakes—that's pretty risky. I live in this day and age. I walk in the streets of Washington, DC at night! That's really risky.

When it comes to the ocean, I want to go. I want to have access, not just to the highest reaches of this planet. In fact, since the first ascent to the top of Mount Everest half a century ago, more than 2,000 people have been to the top of Mount Everest—literally the top of the world. It will soon be half a century since the first successful trip to the deepest part of the ocean. That was the Everest of the ocean, 11 kilometers down—7 miles—the bottom of the Marianas Trench, not too far from the coast of the Philippines. That was nine years before the first footprints were on the Moon—1960 when that took place—13 years after Thor Heyerdahl's expedition across the Pacific with a balsa wood raft. Again, OSHA would not have approved. At a depth of seven miles, two men looked out of the port of the little machine, the bathyscaphe *Trieste*, at a depth of seven miles and a pressure of 16,000 pounds per square inch, in that eternal darkness of the deep sea, except for bioluminescent creatures, which are virtually everywhere in the ocean. They saw eyes looking back. It was a flounder-like fish. And everybody joked, of course, it had to be a flounder-like fish, a flat fish, with 16,000 pounds of pressure per square inch.

But there you are. For about half an hour, almost half a century ago, they had a glimpse of the deepest part of the ocean. Nobody's been back since. How can this be? Presently there are four vehicles that exist that can take people to just over half the ocean's depth—the two Russian Mir subs, the French *Nautile*, the Japanese *Shinkai 6500*. The Japanese tethered robot Kaiko did get some observations a few times in the deepest part of the sea in the last decade, but it was lost at sea last year. They confirmed, however, the existence of abundant and

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diverse life at the deepest part of the sea, and soon, Woods Hole Oceanographic Institution will have, with support from our taxpayer funds, a tethered robot that will, again, go to the deepest sea. But it will take a few years. China is building a 7,000-meter manned sub, and the United States is getting back into the deep sub game when that workhorse of all subs, the *Alvin*, will be replaced in the next few years with a 6,500-meter sub.

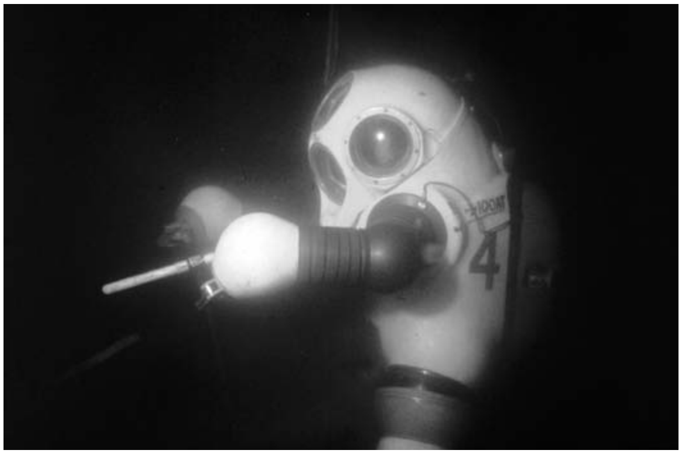
Well, I say, why only 6,500, why 7,000 meters when we're looking at an ocean that is 11,000 meters deep? I want to go to the deepest part of the ocean. I mean, who doesn't? Why wouldn't you want to go? But I'm told, you know, we've got access with a 6,500-meter or even a 7,000-meter sub to about 98 percent of the ocean. So, it's only 2 percent, why worry about that? Well, it's 2 percent—it's an area about the size of the United States and an area about the size of Australia or China, and we'll just write that off. And it's a unique high-pressure realm. Remember, 16,000 pounds per square inch of pressure. Where else on the planet are you going to find forms of life that can survive in a realm like that? It's a place where basic ocean processes are taking place as well, the bottom of the deep trenches where the crust of the ocean is diving under the continental plates.

Well, I've conveyed my concerns about the powers that be that are stopping at 6,500 to 7,000 meters. I say, "Lewis and Clark didn't stop at the Rockies and say, 'That's good enough. Why bother going all the way to the coast?' Sir Edmund

Hillary and Norgay Tenzing didn't stop 98 percent of the way up to the top of Mount Everest, and we didn't travel 98 percent of the way to the Moon and turn around and say, "That's good enough." Or to Mars. You know, we actually have sent probes and landed on Mars, and someday we will get back to the deepest part of the sea. And, frankly, I don't know what's stopping us. Unless there's a certain resistance called risk.

I, like Anne Lindbergh, like many of you here, I suppose, really do want to go. And here's the thing. I'm far more concerned about not taking the risks involved with exploration than risks that are involved with doing what we are doing. I mean, suppose we just get ultrasafe and stay in bed—that's risky too. As an ocean scientist, as chief scientist of NOAA back in the early '90s, they started calling me the "Sturgeon General" because I expressed concern about what was happening to the planet. This is, after all, our life support system. And, as any astronaut will tell you, you learn everything you can about your life support system, and then you do everything you can to take care of your life support system. And we haven't learned a great deal yet about our own life support system. This blue planet—less than 5 percent of the ocean has been seen, let alone explored. And I don't think the risks are really worth talking about when you consider the gains and the risks of not taking whatever modest risks there are out there.

I am concerned about the health of this planet—our life support system—starting with the Earth's blue heart, the ocean. I think of the ocean as the engine that drives climate and weather, regulates temperature, generates most of the oxygen, and absorbs much of the carbon dioxide. It's home for 97 percent of life on Earth, and that's not surprising considering that that's where 97 percent of the water on Earth is. As Chris McKay—one of my great heroes—says, "Water is the single non-negotiable thing that life requires." Huh! There it is.



Exploring in the deep with a JIM suit. (Image ID: nur07562, National Undersearch Research Program (NURP) Collection Photographer: W. Busch)

In the past half century, we've learned more about the ocean than during all preceding human history, but it's not good enough—there's so much more that we need to know. And, at the same time that we've learned more, we've lost more. In the last half century—the last half century!—90 percent of the big fish in the ocean have been extracted. Ninety percent! Think of it. Half the coral reefs are either gone or they're in really a sharp state of decline. Kelp forests from Tasmania to Alaska are not in the same good health that they were 50 years ago. They, too, are in a state of decline. I hope you enjoyed that tasty bit of halibut that you had last night—those of you who consumed it—because they're among the big fish—along with tuna, sharks, swordfish, grouper, snapper, California rockfish—that have plummeted in my lifetime, in your lifetime, because we are so good at extracting things from our life support system before we even understand how it works.

So think about what the risks will be of not taking the relatively small risks involved in exploration today. The chemistry of the planet is changing. What does

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that mean to the little critters that are out there? Especially the microbes that really dominate the way this planet works? Won't take much to set off a whole new suite of events based on the changes in chemistry that are taking place now. Our security as a species is at risk for our reluctance at not taking the relatively small risks involved with what some regard as cutting-edge exploration. As never before, we really do have a chance to get out there and make a difference—and maybe as never again. I want to show you now something to cause you to dream with me about what the potential is. Why aren't we out there in the ocean? Why aren't there fleets of little submarines like there are fleets of aircraft up in the sky? There is a little one-person sub called "Deep Worker", built up in Canada. There are, I think, about fifteen or sixteen of them in operation now around the world. For five years as the explorer-in-residence—what a cool title!—at the National Geographic Society, I had the chance to engage more than a hundred people—scientists, teachers, administrators, paper-pushers, economists—to learn how to drive those little subs. They're so simple to learn how to drive that even a scientist can do it.

And we did it, looking at the coastline of the United States, focusing on the small but promising counterpart to the national parks on land—marine sanctuaries. There are a few. It amounts to less than one percent of our coastal waters, but, nonetheless, we've made a start toward protecting our life support system around this country. By getting into one of these little subs—one atmosphere, no decompression—we could go as much as two thousand feet. It's a start toward the ultimate 35,800 feet—the deepest part of the ocean, 7 miles. Why shouldn't we invest in fleets of little subs that can take anybody who wants to go for whatever reason? Whether you want to write poetry or whether you want to write a business plan or whether you're an explorer interested in science, this is the major part of our planet. It's blue! It's water. And it's largely still inaccessible.

I was among the first in this country, back in the early 1950s, to enjoy using one of the first aqualungs that first came into the country. I salute Jacques Cousteau almost every day for giving me a passport into the ocean, and I love the concept of being able to fly freely in the sea as a diver. And that's what these little subs do, too. As a diver, all by yourself, people say, "Aren't you afraid all by yourself?" Well, again, what else do we do all by ourselves? I love subs of all sorts: 1 person, 2 person, 6 person, 30 person, or passenger subs that take people out into the sea at least down to 50 meters or so these days. What is stopping us from gaining access to anywhere in the ocean we want to go? Anytime we want to go? We need to understand what's out there, what's down there. This is a moment in time—a crossroads in time—when we know that our life support system is in trouble. This part of the solar system is changing, this blue planet, this Earth. With all due respect to our goal of going elsewhere in the solar system to set up housekeeping—and I love the idea of going to Mars, I'd love to be able to go myself and come back—the fact is that, look as far as we might, the Earth is the place that, for the foreseeable future, we have got to come to grips with and take care of it. That's really what is at risk: our future. ■

NASA Image/Renee Bouchard

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Ocean Futures

Ladies and gentlemen, it is a great privilege and honor to be here, and very humbling, knowing who is here in this audience. And many of you I've had the opportunity to meet, and I have a lot of respect for what you do.

The symposium's invitation states that NASA was created to pioneer the future. I will always remember the difficult times of trying to sell television programs with some of the networks in the United States. The people who were putting up millions of dollars were asking my father, "So, Captain, what do you expect to find?" And his answer to those people who were about to make major commitments was, "If I knew, I wouldn't go."

This extraordinary desire to see what's on the other side of the hill is what has animated all of us. This cannot be done if we do not have a commitment to preserve and protect the resources of the present. It is a dream as old as consciousness to explore the stars, so we must continue to explore, but with an equal commitment to protect the quality of life on Earth, which we are not doing. It will do no good to send people into space or underwater if it becomes an escape from intolerable conditions here at home. That being said, as famous a pioneer underwater as my father was, and his team, they took risks they didn't even know

Jean-Michel Cousteau
President, Ocean Futures Society

As an explorer, environmentalist, educator, and film producer for more than four decades, Jean-Michel Cousteau has used his vast experiences to communicate to people of all nations and generations his love and concern for our water planet. The son of ocean explorer Jacques Cousteau, Jean-Michel spent much of his life with his family exploring the world's oceans aboard *Calypso* and *Alcyone*. After his parents' deaths in the 1990s, Jean-Michel founded Ocean Futures Society in 1999 to carry on this pioneering work. Responding to his father's call to "carry forward the flame of his faith," Jean-Michel's Ocean Futures Society, a nonprofit marine conservation and education organization, serves as a "voice for the ocean" by fostering a conservation ethic, conducting research, and developing marine education programs. Jean-Michel has produced over 70 films and been awarded the Emmy, the Peabody Award, the 7 d'Or—the French equivalent of the Emmy, and the Cable Ace Award.

OPENING PHOTO:
The Bahamas viewed from space.
(NASA Image Number ISS007-E-8916)

existed, compelled by the adventure of what they were seeing for the first time. They took those risks because they were inspired by the importance of the realm they had entered, just as space explorers were, are now, and will always continue to be. Having seen the world underwater, my father then dedicated his life to protecting it. He also came to appreciate that everything is connected, and, thus, he became concerned about the water systems of the planet, the land, the atmosphere, and the quality of life for people.

THE PEOPLE WHO WERE PUTTING UP MILLIONS OF DOLLARS WERE ASKING MY FATHER, "SO, CAPTAIN, WHAT DO YOU EXPECT TO FIND?" AND HIS ANSWER TO THOSE PEOPLE WHO WERE ABOUT TO MAKE MAJOR COMMITMENTS WAS, "IF I KNEW, I WOULDN'T GO."

I think NASA is in the same position relative to its view of life on Earth from space. When my father pushed me overboard at the age of seven, I had a tank on my back and, in those days, children did not argue with their parents, so I've been a scuba diver ever since. Some of my earliest views were formed in the middle of the night, when my father would wake me and my brother out of a sound sleep to stand on the terrace in our south-of-France home to look at the sky, full of stars, planets, and the Moon. We were learning about nature firsthand. Jacques Cousteau was a dreamer, full of excitement to explore outer space when it was only the subject of science fiction at the time. Fifty-nine years ago, he pushed me overboard.

I think my father and his team were willing to take great risks, risks they realized they couldn't even describe or predict, because first, looking up at the stars and then into the oceanic abyss, they knew the greater risk was ignorance. This is as true today. Our invitation also asks, "Why are sacrifices made in the name of exploration more notable than the losses incurred in the course of everyday life?" I think it is the nature of our species to focus on drama. We don't accept short-term, immediate, dramatic risks, but long-term, slow, less dramatic yet more important risks we ignore—i.e., species lost, pollution, and reducing the habitability of the planet for life. We get excited about lives lost from short-term, dramatic events, but are oblivious to thousands of people losing lives from the demise of the environmental system that provides them with income, food, and a quality of life.

For example, in the U.S., it is estimated that the amount of oil runoff flowing from urban pavements into the oceans creates the equivalent of an Exxon *Valdez* every eight months, as reported by the Pew Ocean Commission. Yet, not a word reaches the masses, and even if it did, there would be little outcry. Even the fact that six thousand children die every day from lack of access to clear water creates no outrage. We seem to accept, even ignore, these pernicious risks. I think it is the duty of those of us privileged with the ability to explore to point out both the dramatic and the mundane, but certainly more significant, events.

So, how can we look with vision and commitment into the future of space travel? I think we have to do it by mounting rearview mirrors on our spacecraft. By that, I mean that, while moving farther into space, we simultaneously take the opportunity to include equipment that will continue to monitor with greater sophistication the state of the Earth. Basically, we cannot fulfill our dream of exploration in outer space or inner space if home base is unlivable. NASA is powerfully positioned to create what I call the Global Ocean Network, which at our Ocean Futures Society we have started working on in a conceptual phase, whereby it would be a way to constantly monitor from space with an array of vessel buoys, habited buoys, drifting buoys, whatnot, both bringing the dramatic events and long-term trends in the planet's water system. As Sylvia just said, it is our life support system.

This is nothing new. I have a report right here, given to me a few days ago, from a 1971 meeting of my father at NASA Headquarters with Dr. Wernher von Braun and NASA officials. My father presented the case for a global monitoring system "to monitor the primary production of life in the ocean and to monitor the deterioration of life in the ocean resulting from human activities and from natural forces…" His dream was for NASA to launch satellites to monitor sophisticated ocean sensors. Much has been done in this direction, but now it needs to be part of every endeavor. We need to take an aggressive marketing and public relations approach to selling the future and the risk to the public, something we've not done well. We need to engage them in realistically assessing risk and prioritizing issues. We need to motivate and mobilize them to take personal action and political action to ensure we have an acceptable future for our children. The future based on the direction we are [currently] headed is unacceptable.

Jacques Cousteau, the French sea researcher, in 1973, addressing members of the press on his experiences during an Antarctic expedition with the oceanographic ship, *Calypso*.
(NASA Image # 73-H-164)

NASA is in an unprecedented position to participate in necessary new directions. Infusing future space exploration with stewardship of our planet, we will accomplish two things that have to do with risk: We will have upped the ante in terms of what we can gain by risking human life to further our knowledge, and we will have shown our regard for that human life by protecting it in the only place we know it to exist. There will always be brave men and women willing to risk their lives for exploration in outer space and underwater. We need to dignify their courage, and possibly deaths, by making sure we are doing everything to protect not only their lives, but the life-giving system of the planet through their work as well.

I'd like to tell you why we take risks. This incredible planet of ours, the only one with sufficient quantities of water that we know of to have the kind of sophisticated life like we have, has inspired a lot of people like my dad to pioneer.

They didn't know what they really were doing. They were very cautious. And most of them, anyway, stayed alive. But it was touch and feel. It was this unbelievable curiosity that animated them and opened the ocean world to millions of people.

In South Africa, I was taught to dive and hang on to the back of the dorsal fin of a 14-foot great white shark. Was I taking risks? Very calculated risks, much less than when I cross Fifth Avenue in New York. But in the process, we're making people understand that these animals are part of our system.

Was I taking risks when I wanted for the first time to go down with a ship, sink with a ship, a Russian frigate that was made into a dive site? I always wondered, what happened in the minds of those people as they sank with their ships, the captains, the people in charge? A few months ago we were in the middle of the Pacific working on an island, Laysan, where nobody lives, and finding all our refuse. Fifty-two countries were represented there with probably tens of thousands of tons [of refuse] just lying there with fishing nets and debris. We are using our ocean, we're using our own home, as a garbage can, a universal sewer. At some point nature will say, I can't handle it anymore, and we are getting signs of that today.

I believe that exploration and taking risks is what is going to change the face of the planet today. We have new equipment, free breathers, new fins designed by imitating the flip of an Orca, new lights, new submersibles, new communication systems which, as Sylvia just rightfully said, will allow us to explore not just the five percent we've explored, but a hundred percent. And that's what's going to make us do the right thing. Because how can we protect what we don't understand?

So this risk we're taking is for the bettering of the quality of life for the human species on the planet. Those sharks we were diving with at 200 feet of depth, they don't care. We do. We want them to stay there just like anything else.

I will never forget the comparison that my dad made one day when he told me, "You know, the planet is like an airplane with wings. Every time you remove a rivet you are removing a species. At some point, it may just collapse." We don't want to go there.

And the decisions that our brains, that our industries, and political representatives anywhere in the world will make will allow us to fulfill our dream and take calculated risks. And that, I believe, is what animates every one of us here. I have no job, I have a passion, and I will not retire until I'm switched off. ■

NASA Image/Renee Bouchard

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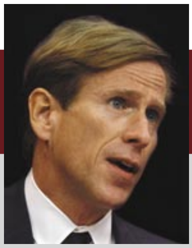
Exploration and the Risk-Reward Equation

Defining and controlling risk in exploration operations is a tough and continuous challenge that requires the application of a range of methods from the qualitative to the quantitative, and, ultimately, to be successful, requires consistent application of informed good judgment.

We've already heard a lot of very insightful themes from the previous speakers, and you're going to hear some of them again from me, but possibly from a slightly different perspective. For my entire adult life I've been in relatively risky professions, starting out as a scuba diving instructor and boat captain in the Caribbean, where your job is basically to keep people from killing themselves, and you see it all, from people who sit on sea urchins and scream and spit out their regulator and their false teeth, and then go shooting to the surface, to people who go chasing after aggressive tiger sharks. So you learn to expect that anything can happen.

After that, I worked as a commercial deep-sea diver doing subsea construction in the offshore oilfield, and then, later, as vice president of the world's largest subsea contractor. Currently, I'm an astronaut, and involved in doing high-risk human research for space decompression procedures.



Michael L. Gernhardt, Ph.D.
NASA Astronaut

NASA selected Michael Gernhardt as an astronaut in March 1992. His technical assignments have included development of nitrox diving to support training for the Hubble Space Telescope repair and a variety of Space Station extravehicular activity (EVA) developments; spacecraft communicator (CAPCOM) at Mission Control Center, Houston, during various Shuttle missions; and leading an international research team in developing a new exercise prebreathe protocol that improved the safety and efficiency of space walks from the International Space Station. Gernhardt presently serves as a member of the astronaut office EVA branch and as principle investigator of the Prebreath Reduction Program and manager of Johnson Space Center's Environmental Physiology Laboratory. A four flight veteran, Gernhardt has logged over 43 days in space, including 4 spacewalks totaling 23 hours and 16 minutes. He was a mission specialist on STS-69 in 1995, STS-83 in 1997, STS-94 in 1997, and STS-104 in 2001. Gernhardt is assigned to the crew of STS-119.

OPENING PHOTO:
Equipped with SCUBA gear in waters off the Florida Keys, the NEEMO 5 crew members congregate near the viewing port of the Aquarius research habitat. (NASA Image # JSC-2003-E-45591)

As a professional, it's important that you address the risk-reward equation. Basically, that equation states that the utility, or the degree of success, is equal to the probability of success times the reward, minus the probability of failure times the cost. As a professional, if you don't balance this equation properly and end up most of the time with a really large, positive number, you're either not going to live very long, or, if you're in business and you're killing your people, you're not going to stay in business very long.

Commercial diving is potentially a very dangerous business, but, in fact, it's actually safer than many forms of nonprofessional scuba diving, because we understand that it's risky and we plan for those risks. Some of the nonprofessionals tend to focus more on the reward component of this equation. It would be really neat to dive on this wreck or really great to go in this cave. And, unfortunately, they don't understand the risk side until it's too late.

As individuals involved in these operations, it's vitally important that you understand and accept the risks that you're getting into. And it's also important that the individuals have direct control of the risks through their own actions.

Commercial deep-sea diving is potentially very dangerous. Some of the work that we do includes very complicated construction tasks that would be dangerous on dry land. An example is a hyperbaric welding job, where, in order to do code-quality structural repairs of offshore platforms, we actually have to weld in a dry environment, because in wet welding, the water quenches the weld so fast you get hydrogen embrittlement. So we have to design these multipiece habitats that we have to install around the tubular truss structure of the platform, install seals, dewater the habitat, and then go inside and weld in a dry environment.

These are challenging operations at very high forces. A lot of time you're working in current conditions, at close to maximum aerobic capacity. These operations would be dangerous on dry land, but we do them at depths of up to 1,000 feet, under extreme physiological stresses, working in a dynamic, harsh environment that is capable of radical changes over short time periods. And many times, you're working in limited or zero visibility on the muddy bottom. And, so, you've got to realize that that's risky, and plan and address those risks.

In my mind, I divide risk into two categories. There's what I would call the corporate or programmatically controlled risk, and these risks relate primarily to the design of the equipment, the degrees of redundancy, the reliability, things of that nature. An example is a saturation, helium-oxygen saturation, diving system. And if you're not familiar with saturation diving, we use this method to increase the efficiency of the amount of bottom time we get for the amount of decompression time. If we were to work at 500 feet for 30 minutes, it would take over 24 hours to decompress. Once you stay on the bottom 24 hours or longer, the partial pressure of inert gas in your inspired breathing mixture comes to equilibrium with the tension of gas dissolved in your blood and tissues. Then your blood and tissues will not uptake any more inert gas, and it will take 5 days to decompress, whether you stay on the bottom for another minute or another month.

So, we actually live in these pressurized habitats on the deck of the vessel, breathing a helium-oxygen mixture. At 1,000 feet it's less than one percent oxygen. Then we transfer under pressure into a diving bell, we make a seal on the bell, the bell is deployed overboard, and acts as an elevator to transport the diver to the subsea worksite. Then we lock out of the bell, do eight hours work, reenter the bell, and make a seal-return to the surface under pressure where we transfer into the living chamber on the deck of the vessel or platform. With a six-person crew, we do 24-hour-a-day operations. That results in about 20 hours of working bottom time per 24 hour-day. We spend a month under pressure, so the working-time to decompression-time ratio is about five, compared to the surface diving position where you're less than point one.

This is a very efficient form of diving; it's very challenging with respect to the life support systems. Minor changes in the oxygen percentage can mean the difference between hypoxia and acute oxygen toxicity. Same kinds of limits on the carbon dioxide. Temperature and humidity are very sensitive at these extreme pressures and gas densities. A temperature swing of a few degrees, a few percentage points of relative humidity change, is the difference between comfort and discomfort. And larger swings than that are life and death.

On top of that, we're locking out, we're working in an oilfield environment, where you can bring trace contaminants back into the habitat. So all this has to be accounted for ahead of time, and controlled, and if you do a good job at the corporate level, the equipment and procedures are safe, and you're happy to go use it. On one of our diving support vessels, we actually have a 16-person saturation habitat built in below decks. It's very much like a space station, with living quarters and node. There's a thing called a moon pool, we deploy the bell through the bottom of the vessel. So we do all kinds of very challenging operations, including some very unique decompression procedures.

I had the opportunity to work with a man named C. J. Lambertsen, who actually invented the oxygen rebreather, and is considered the founder of the Underwater Demolition Team (UDT). He actually worked for the OSS in World War II, and he was the medical director of the company I worked for, and I worked closely with him for almost 25 years now. Very wise guy, very smart, very intellectual, very good operator. And his attitude was always, what do we have to do? Now, how do we do it safely? And that's the right question to ask.

The other question is, what can we do safely? And if you ask that question, you don't have the focus. I mean, there are a lot of things you can do safely. You can watch television, you can go bowling. Oops, no, you might hurt your back. So you see where that's going. So it's important to define what you want to do. Then you have clear focus, and you can address the risk and do it safely. If you don't have a clear vision of what you are attempting to do, then its difficult to analyze and control the risks, and, ultimately, you can end up being less safe, even though you start with a more conservative attitude.

The other form of risk that I categorize is what I call the individual or team-controlled risk. And even though the company might provide you with safe diving equipment and methods, we're doing heavy-duty construction in a dynamic environment, and there are all sorts of risks that are directly in the control of the diver on the end of the hose and the topside team supporting him. One example is a platform repair we did off Peru. The platform was falling down, and we had to burn off the old parts of the platform, and then install these clamps and braces and, basically, rebuild the entire platform underwater. A lot of times, we're working in two or three knot currents with heavy surge conditions. In order to rig the repair braces and install them underwater, you've got, sometimes, two crane lines and four air tugger lines that you have to direct in order to transfer the multiton brace into position at the underwater worksite. You're down there in these heavy currents and surge with limited visibility and your life support umbilical [is] potentially in the middle of all of these crane and air tugger lines, and if don't have good situational awareness, you can get your umbilical hose, hand, or arm in the middle of the trajectory of these swinging flanges and lose your arm, or your fingers, or cut your umbilical hose. And, so, you have direct control over these risks.

"SO IT'S IMPORTANT TO KEEP FOCUSED ON WHAT YOU'RE DOING, AND BE CONFIDENT AND AGGRESSIVE, AND UNDERSTAND THE RISKS AS BEST YOU CAN AND THEN GO DO IT."

I don't know how NASA's safety would quantify this kind of operation. We typically approve things by testing or analysis. I don't know what you test here, because every circumstance is different, impossible to quantify, and, generally, unrepeatable. And, so, these risks are very much in your control, and your skill, and the supervisor's assessment of your capabilities, is the only level of control of these risks, along with very good planning and teamwork.

One of the observations that I've made is that to do this kind of stuff safely, you have to have the right attitude, you have to plan it, and you have to work with your team, your topside team, and the people controlling all these crane lines, and you have to go in with a good plan, and you have to be confident and aggressive.

And the people that I saw getting hurt were the people who had checked out a little bit. Their heart really wasn't into it, and they wouldn't attack the pre-dive planning, and then they'd get in and they'd hesitate at the wrong moment, or something like that, and they would have the accident.

And I think the same observation would be true for an organization. If you become so risk-averse that you indiscriminately apply your resources to controlling trivial risk, then you don't have those resources to apply to the important risks, and you lose your focus, and you really don't accomplish that much, and, frankly, you're probably not that much safer. So it's important to keep focused on what you're doing, and be confident and aggressive, and understand the risks as best you can and then go do it.

We heard a lot of interesting and eloquent quotes from explorers, and I have to tell you one of my favorite quotes was from my first Shuttle commander, a guy named Dave Walker. Dave is no longer with us, but he was a remarkable human being and a great team builder. He actually christened our crew as the "Dog Crew," and he gave everybody a dog name. The only condition was you couldn't like your dog name. So, being a rookie and a diver, I was Underdog. His call sign was Red Dog. Dave said to me, "You know, Underdog, it's a fine line between bleep and bleep hot." I can't say it exactly the way he said it. The bleep starts with an "S." Dave had probably known both sides of that line, so he really understood that. It is a fine line. It is a fine line between being a cowboy and taking too many risks, and then, on the other side, being so risk averse that you don't get anything done and you're not as safe as you should be.

Now, as far as the risk-reward equation and the commercial diving industry, we have to be safe or we don't have a business. It is the right thing to do. You don't calculate that we're willing to lose this many people or anything like that. You do the very best you can to make things safe. You also make them cost effective and efficient. What we have done over the years is, we started out with the divers in a hands-on environment. We have slowly evolved the human back from the direct operational environment. Instead of divers having to go into saturation and incur all these physiological stresses, we had one-atmosphere dive suits. That was one step. We then stepped further back from that with the introduction of remote operated vehicles [ROVs]. I was in commercial diving in the late '70s and early '80s when these became widely used. It was pretty comical at first, because they were way oversold. The salesman would promise the oil companies that you could do all kinds of things. We actually ended up making a lot of money as divers rescuing these things when they failed or got fouled up on a structure. One of the key things that we learned is that it's not so much the capabilities of the human or the robot; it's both sides of the interface, which includes how you design the tasks to be compatible with the diver or the robot. The integration of both sides of this equation results in a work system versus just a diving suit or a robot. What we did was work with the oil companies to reengineer the subsea equipment so that we could work on it easily with ROVs. We ended up actually being able to produce as efficient work with these ROVs today as we could with divers in previous years. An example is what we call the bucket. We actually made the task so simple that the only task was to dock the ROV into this conical interface. We had different tooling packages inside that would do different things, ranging from small and large valve actuations to mating electrical and hydraulic connectors, but to the operator, the task was always the same, dock the ROV into the bucket. So you try to keep it simple.

When you keep things simple, it actually gives you more brain cells to apply to situation awareness to know how to stay out of trouble. We have actually evolved some of these concepts up to the Space Station, with the microconical interface. So, the message here is to keep the task and operation as simple as you can and, ultimately, that makes it safer, because you have more reserve capabilities and situational awareness to deal with the unexpected. When you plan an operation right at the limits of your capabilities, your safety margins go down.

People always ask me, "Was it more dangerous in commercial diving or the astronaut business?" I think the answer to that is that in the space business, getting to the work site is a lot more dangerous than riding the boat out and coming back. But in commercial diving, once you're at the work site and dealing with all these dynamic forces and physiologic stresses, it is probably riskier than doing a spacewalk.

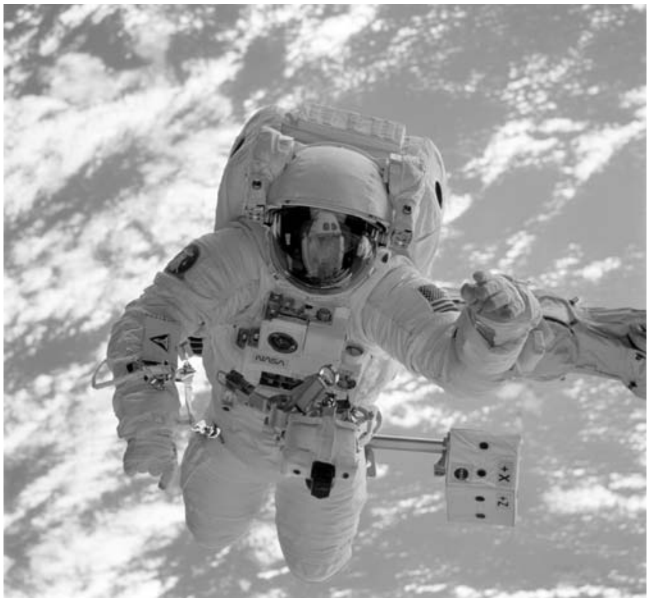
One of the things I think will happen, though, as we evolve to planetary exploration is that instead of training for a whole year to do a spacewalk and having a whole ground team behind you, we're going to be doing EVA [Extravehicular Activity] every day, with a plan that has been developed, at best, the day before and one that is likely to change many times during the course of the EVA. The balance of risk is going to shift between the corporately controlled risk on the redundancy of the vehicle to the personally controlled risk when you're doing these EVA operations. We need to have people who can make good judgments and good decisions in a relatively unstructured and dynamic operational environment.

I participated in one of the first NEEMO (NASA Extreme Environment Mission Operations), which is a program we have going with NOAA [National Oceanic and Atmospheric Administration]. The underwater habitat they have off the Keys is a great analogue. We actually lock out, do coral reef science, and spend nine hours a day in the water. They have remote way stations where you refill your tanks. I have proposed that this is a great analogue to use to parameterize that operational space. How far away from the habitat are you? What are your consumables? How long will it take you to get back to the habitat, and how much air will you consume? You have to make all these real time decisions about when to refill tanks, when to start and stop working, when to head back to the habitat, et cetera. The NOAA team has really tight flight rules. If you come back to the habitat with less than 500 psi or one second beyond your flight plan, you're busted. You're not going to dive anymore. It really builds good decision-making. They have done over 27,000 excursion dives with a perfect safety record.

The notion would be to parameterize this operational space, and then ask yourself the question: If we're going to work on the Moon and we want to explore a 200 kilometer radius, then what life support do we need? How fast do our transport vehicles need to go? Where should the way stations be? There is a lot that we can learn from land and subsea analogues that we should be applying to our mission design well before we set foot on the Moon or Mars.

I am going to transition quickly from subsea to space on the topic of decompression. I will also talk about the difference between qualitative and quantitative risk control. We have to decompress in space because we work in low-pressure space suits, and we want the pressure to be as low as possible so that we have minimal forces and torques across the suits so we can work. We actually have to get rid of nitrogen much the same way a diver does.

On the trials of the Shuttle decompression procedures that we have all used, we had 25 percent decompression sickness. You ask yourself, is that acceptable or not? It turns out there are some things about altitude DCS (decompression sickness) that are much different than diving. If you talk to the divers here, they will say you've got to have way less than five percent. In commercial diving, we had about 0.01 percent. Altitude decompression sickness is different, primarily because you pre-breathe the oxygen and undersaturate your brain and spinal cord, so we don't [have] nearly as many serious symptoms of DCS that we see in diving.



Astronaut Michael L. Gernhardt, mission specialist, is pictured during the 16 September 1995 extravehicular activity (EVA) which was conducted in and around Space Shuttle *Endeavour's* cargo bay. (NASA Image # STS69-714-046)

When they did the Shuttle ground trials, they came up with 25 percent DCS, and they had a committee come in and they said, "Well, what do you think? Is this safe or not?" You can find anybody to say it's safe or it's unsafe. It turns out that we have not had any decompression sickness in flight, probably because the ground model was not that accurate. I don't have time to go into all those details, but the point is that it was the assessment of acceptable risk was very subjective.

When I started the pre-breathing production development for the procedure we are now using on the Space Station, I took a whole year with a large team to define what acceptable risk was. I pulled in the Navy and the Air Force, the flight directors, who are great guys, who are really great at analyzing data and making decisions, the flight surgeons, and the astronaut office. When we had the first meeting, I said, "Everybody in this room has an opinion about what acceptable DCS risk is. Recognize it is only your opinion." We proceeded over the course of a year to pull in all the data we could, analyze the data, and when we extracted the last little bit of information out of that, we finally made the decisions.

There was a lot of talk yesterday about staging things. We actually staged into this. You couldn't get a consensus right off the bat as to what acceptable DCS risk was, but I took the tack of saying, what's the highest risk we could have and still build the Space Station? We had a policy that if you had Type I DCS on an EVA and it resolved, you could go EVA again in 72 hours. This was consistent with Navy and Air Force procedures. If you have the second Type I hit on this same mission, then you were out. If you had Type II, serious DCS, you were also out of the rotation.

We then did a Monte Carlo simulation of the entire Space Station assembly and maintenance model, applying this policy and subjecting it to the constraint that we be 95 percent confident that we would always have two crew members to do an EVA. That defined the uppermost risk we could have. We then looked at other factors and actually ended up picking a level of DCS risk of 15 percent at upper 95 percent confidence level, which, [as it] turns out, is below a threshold where there has ever been a report of Type II DCS in our database. We do these trials with human subjects. Subject safety is our number one priority. We have defined very explicitly what the accept conditions are. Even though the research is difficult, it is pretty easy to make a decision, because we have prospectively defined the acceptable risk criteria. You design the experiment, you do the trial, and, if it meets it, you're great. If it doesn't, you reject it and test the next protocol.

Some of these quantitative risk definitions and control techniques would be applicable to other aspects of vehicle and mission safety design. Statistics are a good tool, to be used in conjunction with informed good judgment, not a replacement for it. It's a fine line that we will have to walk as we move forward with the next generation of exploration missions. We will need to understand and accept that they are risky, define clearly what we want to do, define and control the risks as well as we possibly can, and then go do the mission recognizing that we have done everything practical to control the risks, but that we will never totally eliminate them. ■

NASA Image/Renee Bouchard

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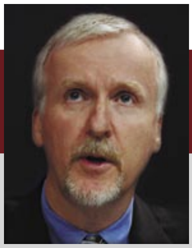
Titanic and Other Reflections

I am also honored to be part of this august panel, which includes two of my heroes from the undersea world, and some of the people I'm just meeting today. We live in an age when the land area of our planet has been explored, mapped, imaged, settled, and exploited for whatever it has to offer. It's definitional that what remains to be explored are the most remote, inaccessible, and inhospitable parts of our world, or places that are not a part of our world at all. This basically means that the easy stuff has been done, if you want to consider polar exploration and all the great pioneering work in the ocean the easy stuff. The hard stuff is in front of us, and it means we are now confronting even more hostile and extreme conditions and requiring more sophisticated technology and support systems in order to do our exploration. Correspondingly, we are facing more complex and subtle forms of risk than ever before.

I have lived with risk for my entire professional career as an action film director. I regularly asked people, with a completely straight face, to set themselves on fire, to flip their car over, to leap out of an exploding building, to ride on top of a tractor-trailer truck that's on its side skidding, to fly a helicopter underneath an overpass with two feet of clearance on either side of the rotor tip, and even to ride a sinking ship down underwater.



James Cameron

Writer/Director, Undersea Explorer

Born in Kapuskasing, Ontario, Canada, James Cameron grew up near Niagra Falls. In 1971, he moved to Brea, California, where he studied physics at Fullerton College while working as a machinist and, later, a truck driver. The1984 sleeper hit, *The Terminator*, launched his directorial career. Since that time, Cameron has served as writer, producer, director, and/or editor on such films as *Rambo: First Blood Part II, Aliens, The Abyss, Point Break, Terminator 2: Judgment Day, True Lies,* and *Titanic*. Cameron's films have also earned numerous nominations and awards from a variety of organizations, culminating in *Titanic's* 11 Academy Awards, including Cameron's three Oscars for Best Picture, Best Direction, and Best Editing. In 1995, Cameron made 12 dives to the *Titanic* in preparation for his feature film. Cameron has made a total of 38 dives in the Mir submersibles. His most recent expedition to the hydrothermal vents is the subject of the IMAX film, *Aliens of the Deep*.

OPENING PHOTO:
Part of the railing from the bow section of the *Titanic*. Courtesy of James Cameron.

In twenty years of directing stunts and action and pyrotechnic effects, I've never actually had a serious injury on the set. That is because of application of a fairly rigorous and disciplined process. It is not as institutionalized as it is with NASA, but it has its own special rigor. Before any major stunt, or gag as we call them, I would walk the set myself, looking at every piece of rigging and turning over every possibility in my head. At that moment on a shoot when all the lights and the cameras are set up, it is the culmination of months of planning, engineering, testing, and rigging. The industry's leading experts up to that point have done it all. (I would just like to point out that the failure of the Genesis spacecraft was not due to the Hollywood stunt pilot. Of course, now we know that the science has been recovered, so it's all good.)

These experts have decades and decades of experience doing stunts, explosions, car gags, fire, and whatever it is that we might be doing. But still, even after every single one of these people has signed off, I walk the set. I just call a complete hold. I walk the set. I look at the rigging. I ask questions. I think about it: What if this happens? What if that happens? Even though we have been over it and over it, I call that last minute hold, and I walk the set. I'm looking for something which is something that I've over the years come to call the x-factor, some previously unseen detail or some exotic combination of variables which could cause the stunt to go horribly wrong.

I guess my point here is that the personal touch is critical, and taking individual responsibility is critical, for everybody in the chain. Systems protocols and institutional checks and balances are important, and they add great robustness to risky operations. However, those very checks and balances can often inhibit individuals from speaking up or taking action because they make the assumption that someone else has approved it. Someone else is going to catch it. Someone else has responsibility, and they don't catch it before it's too late.

[When] we made the movie *Titanic*, we began that production in a very unusual way. We actually dove to the wreck site of *Titanic* twelve times. It's in 12,500 feet of water in the North Atlantic. We set ourselves some pretty ambitious goals. We were going to build a new camera system so that we could operate a 35mm movie camera outside the submersible, seeing ambient pressure at 5,500 psi. We were going to build new lighting equipment. We were even going to build our own remotely-operated vehicles so we could explore the *Titanic* wreck internally. I had some experience as a project manager developing new technology for underwater filming on the movie *The Abyss*, and that prepared me, to a certain extent, for the difficulty of engineering this new equipment. Nothing prepared me for the chaos introduced when we took that whole circus to sea on a research ship. We weathered three hurricanes and multiple equipment failures, but we managed to prevail and get the images of the wreck. In that process, I got bitten by the deep ocean exploration bug.

After the success of *Titanic*, the movie, I found myself less interested in Hollywood filmmaking and more interested in the challenges of ocean photography and exploration. So, over the next few years, we developed new images and robotic exploration technology. Then I had to go out and raise the money by making films, in order to pay for it. So we wound up returning to the *Titanic* wreck site in 2001, because I figured if I couldn't raise money to go to the *Titanic* wreck I couldn't raise money to do anything. We took our spanking new 3-D digital imaging system to capture the coolest stereo images of the wreck that we could before it disintegrates, and we made a film called *Ghosts of the Abyss*, which was for the IMAX 3-D theaters.

We also created two very tiny and advanced ROVs [Remotely Operated Vehicles] which could fly untethered inside the wreck. They were untethered in terms of a power umbilical, but they had a data tether, which was a spool of fiber optic, kind of like a wire-guided torpedo. We were able to explore the wreck, room by room and deck by deck. These were launched from the submersibles after we landed on the *Titanic* wreck, and they were flown inside the wreck by myself and two other pilots. With these bots, we were able to capture some pretty amazing images inside the wreck in spaces which could never have been seen by human eyes and which probably will never be seen directly by human eyes. We were able to reveal in the lights and video cameras of these tiny robots a kind of lost grandeur of *Titanic*, which still exists deep inside that wreck.

> *TITANIC* HAS A VALUE AS A KIND OF PARABLE. THE LESSONS LEARNED ARE STILL VALUABLE FOR US IN OUR CONTINUING EXPLORATION OF THE SEA AND OF SPACE.

For me, that was the greatest adventure imaginable. If I wasn't hooked before, I was certainly hooked then. Of course, all the time I was very cognizant of the risks and, as the person heading the team, the expedition leader, so to speak, it was my responsibility. The buck stopped with me, so I was continuing to apply my lessons learned from my underwater motion picture filmmaking experience, to this new realm. Of course, we had a lot of problems, and we had equipment failures, and we got hit by another three hurricanes. Then the September 11th attacks cut short our expedition. It was certainly a bizarre and ironic experience to be, literally, down at the bottom of the ocean, at the site of the defining disaster of the first part of the 20th century, while probably the defining disaster of the first part of the 21st century was taking place over our heads without our knowledge.

Having made 24 dives at this point by the end of the second expedition to explore the *Titanic*, I am now pretty continuously mindful of the lessons of *Titanic* as I continue with other exploration projects and any projects involving risk of any kind. The lessons learned from the sinking of *Titanic* caused sweeping reform of the maritime safety code in its time. But in the abstract, *Titanic* has a value as a kind of parable. The lessons learned are still valuable for us in our continuing exploration of the sea and of space.

Titanic was sunk primarily by institutional momentum. Just as the inertia of the ship was too great for the crew to be able to turn it in time to avoid hitting the iceberg, the inertia of their methodology was at least equally responsible for the collision. It was the policy of sea captains at that time to maintain full speed until they'd spotted the ice and then slow down only when it became absolutely necessary. This was for economic reasons, reasons of straight commerce. This was simply how it was done.

"THERE ARE A FEW INTERESTING PARALLELS BETWEEN THE SINKING OF THE *TITANIC* AND THE LOSS OF THE *COLUMBIA* SPACE SHUTTLE AND HER CREW. IN BOTH CASES, THERE WERE UNHEEDED WARNINGS. IN BOTH CASES, THE WARNINGS WERE DISMISSED, NOT OUT OF NEGLIGENCE, BUT FOR REASONS THAT MADE SENSE BASED ON THE EXPERIENCE AND INSTITUTIONAL MEMORY AT THAT MOMENT."

The *Titanic's* captain was due to retire after this one last prestigious voyage, after a long and unblemished career. He was captaining on the maiden voyage of the largest vessel ever created. His lifetime of experience taught him that on a crystal clear night, in a flat calm ocean, he was safe maintaining full speed, despite the Marconi-gram sitting in his pocket warning of a huge ice field ahead. With a warning to the officer of the watch to be extra vigilant, he went to sleep as the ship barreled on toward its fate. Now, was this arrogance or hubris, as many have said? I don't think so, not really. It was simply business as usual. These new ships didn't handle like the previous ones. They took longer to stop or to turn. So, everything he knew was actually wrong in that exact circumstance. The old operating methods didn't really apply. The conditions had changed, but the methods hadn't kept up. It also required an unlikely combination of elements to create the disaster. It was a typical cascade failure where you had a number of things in series, all of which had to happen in that unique combination. The flat calm of the ocean meant that no swells were breaking against the icebergs, which reduced the ability of the lookouts to see the icebergs in the dark. The general mistake made by the crew was to underestimate the perversity of the ocean, even when it seemed at its most benign.

There are a few interesting parallels between the sinking of the *Titanic* and the loss of the *Columbia* Space Shuttle and her crew. In both cases, there were unheeded warnings. In both cases, the warnings were dismissed, not out of negligence, but for reasons that made sense based on the experience and institutional memory at that moment. In the case of *Titanic*, the crew was well aware, because of wireless messages, that the ice lay ahead, but it was because it was the way it was always done that they proceeded at full speed toward the ice field.

With *Columbia* it was known from many past missions that the foam could separate from the external tank and possibly strike the orbiter, but that problem had been analyzed twenty years earlier and dismissed as a serious threat to mission safety. When foam was observed possibly striking *Columbia* during the launch, some engineers were concerned. But because this was the way we've always done it, the warnings didn't propagate up the chain of command with enough force to change the outcome. So cultural momentum and institutional memory had worked against *Columbia* just as they had worked against *Titanic*.

Another parallel is that in both accidents an unlikely series of events were required to cause catastrophe. With *Titanic*, it was the unlikely event of the very first iceberg that they spotted, the very first one out of a huge field of ice, happening to be exactly in the track of the ship. This was occurring on a night without the slightest swell activity to assist in spotting the berg in time. And all of this was happening to a new, large class of ship whose crew was inexperienced in managing it in fast turns and sudden stops. With *Columbia*, it took the foam strike incident, but then compounded it by the fact that this was one of the very few missions in recent years that did not go to the ISS [International Space Station]. Had it been a mission to the Space Station, it is likely that the Station crew would have seen the large hole in the leading edge of the wing during the operations. Then the station could have provided safe haven for the *Columbia* crew while everybody scrambled to launch a second orbiter to bring them all home safely.

So the vanishingly small possibility of a foam strike event actually damaging a flight-critical component was coupled with the statistically low probability of a non-ISS mission to create a disastrous outcome. These low-probability, high-consequence events are the hardest to plan for and prevent, especially when it requires a number of low-probability events in combination in order to create a threatening scenario. *Titanic* teaches us to be constantly vigilant, to assume nothing about our methodology, to constantly ask the question "What are we doing wrong right now?"

I've lived with the lessons of *Titanic* and they've informed my judgment on subsequent expedition projects. After our second expedition to *Titanic*, we looked for other projects with more and greater challenges, of course. The following spring we imaged the wreck of the *Bismarck*, which is 16,000 feet down in the North Atlantic. Then, we followed that up with stereo imaging at five hydrothermal vent sites along the mid-Atlantic ridge. We were pretty excited by the imaging results from that, and I decided to make a second IMAX 3-D film about the life surrounding that hydrothermal vents. It was my intention with this film to draw a kind of sea/space connection, on the basis of a kind of ocean analogue, where we would bring NASA experts in analogue missions and let them draw the parallels between undersea operations with multiple vehicles deploying robotics. The submersibles would be like a Mars surface rover on a traverse being deployed from a habitat or a base camp for which the support ships or the surface ships were the analogues for that. But we were also drawing a connection between the types of life that existed in these chemosynthesis-based environments down at these hydrothermal vents with the kind of life that we might encounter in extraterrestrial hydrospheres; if we were to find subsurface water on Mars, if we were to find evidence of ancient life on Mars, it might have originated in hydrothermal communities. If Mars was once covered with water or had a lot more water, that water may very well have been under ice, it may have been denied the ability to photosynthesize, it may have had to live within a chemosynthesis-based environment.

When we go to Europa, we may find evidence of life there, again, probably subsisting on a nonphotosynthesis basis. So we draw the sea/space connection in that film. I just thought I'd point that out since it's a room full of space buffs and we're an ocean panel—that there's a message there.

DEEP ROVER, Deep Ocean Engineering's one person sub, dives to 300 meters. (Image ID: nur07547, National Undersearch Research Program (NURP) Collection. Photographer: T. Kerby. Credit: OAR/National Undersea Research Program (NURP), University of Hawaii)

In the process of making this film, I've formed a partnership to buy and operate two deep rover submersibles, which are actually codesigned by Sylvia Earle. They have a depth rating of 1,000 meters. They are wonderful subs. You sit inside an acrylic sphere and you feel like you're in a kind of vacuole within the ocean where you have unlimited visibility. You feel much better contact with the environment than you do looking through the small port windows of a typical deep submersible.

Now, previously, we'd been working with the Russian Academy of Sciences and with their Mir submersible operation, which is a two-sub operation. I had a pretty good understanding of the working systems of those subs and of how the submersibles were operated and how two subs are operated in tandem with each other in diving ops. But I was certainly in for a very rude awakening by just how difficult it is to operate a manned submersible system when you're starting from scratch and when you're the one in front of whom the buck stops.

Now, we began by assembling a new team to operate and maintain the rovers and these were gathered from established submersible operations around the U.S. and Canada. The first task was to tear the subs down to their frames for ABS [American Bureau of Shipping] certification. Then we had to make all the modifications to adapt our 3-D digital technology with the [pan and fill] systems and our special lighting and all of that to the submersibles. That was certainly a daunting task. It took about six months, and we were barely re-certified in time for our filming operations.

So, we took our beautiful new subs to sea and met with the Russians out in the middle of the ocean, literally rendezvoused two ships in the middle of the ocean at the mid-Atlantic ridge. We dove them together in a joint diving operation with the Mir submersibles. This culminated with one dive where we actually had four subs rendezvous at the bottom in 870 meters of water at a site called "Lost City," which is a low temperature hydrothermal vent structure, a very interesting place.

This operation was very complex logistically because it involved the creation of new operational protocols for the launch and recovery of four subs in the same theater of operations at the same time. Tracking, communications, surface ship operations, the number of submersibles in the water made all these significantly more complicated. This had ramifications through every kind of contingency you could imagine. It wasn't just twice as complicated as operating two submersibles—it was some multiple. There was some square law at work there. Also, we were dealing with underwater communications, which, if any of you have done this, you know that such communications can be spotty at best, and we were dealing with them in Russian and English between four vehicles at the same time on the same frequency.

So, we had to go through a pretty rigorous process of defining our comms protocols before the fact. It was only because we had a good, long, healthy working relationship with the Russians that made that possible. I found that the principles of risk management and safety assurance that I learned as a film director were actually transferable to these new situations, at least at an abstract level, and certainly at a motivational level for myself, in terms of applying the same kind of energy and passion to the safety of the operation as to the aesthetic results of the film making. Now, obviously there's a very extensive body of established procedure for submersible operations, and we studied that pretty rigorously, and we selected our team members accordingly on the basis of their experience with manned submersible ops. But it seemed like almost everything that we were doing was unprecedented, and it was often difficult to find any kind of existing guidelines in the literature. Often, we were making up our own protocols in terms of what the safe procedures were for the launch of multiple subs or the manner in which we could descend them together for imaging purposes—sometimes only a couple of meters apart, how we could operate them on the bottom (proximity operations), how our acoustic comms would work during the dive, how we would work on the bottom with four subs together and a deployed ROV in the same area—a tethered vehicle.

We were able to pull on our experience from past dives, and we were able to anticipate and talk through in advance most of the contingencies that might arise on the dive. Because of the complexity of our dive ops, we always preceded each dive with a joint dive ops meeting between the Russian group and the American group. I call it the American group, but it was really a mixed group of people from Australia, Canada, and everything else. The Russians called us the "American group."

We used models of the submersibles to talk through the maneuvers. The process there was very simple. Here is a model of your sub. You are the pilot of the sub. You move it. I will give you a voice command. You move that model the way you think what I am telling you to do should result in action. This worked very well. So, literally, it would be, "Hands off. Okay, I want you to do this. I want you to do that." If they couldn't visualize it on dry land where we could hear each other perfectly, then it certainly wasn't going to be any better down at the bottom. Until we figured out what message for voice communications was going to foul us up on the bottom, we wouldn't go into the water. That was one technique.

We had perfected that in doing our wreck dives where we had the wreck as the central focusing element for what we were doing. It got more complicated when we went to these vent sites, and we were unable to physically model the vent sites. We had, in some cases, good microbathymetry, and, at the very least, we had some decent site maps. We would use those as guides, and people would fly their models. We always knew in advance what we were trying to accomplish. This briefing would then get synthesized into a dive plan document, which was distributed to all of the various crew members. You have to appreciate that we had two observers and a pilot in each Mir, so that's six. We would have an observer and a pilot in each of the deep rovers, so an additional four. Ten people were all going in[to] the water, all having to know exactly what they were doing on a daily basis. An interesting lesson here was that the task loading from a planning standpoint became greater than the task load on the actual dive. In fact, I wound up getting most of my sleep during descent and ascent because I was spending the night working through the documentation for the dive the following day. The pace of operations was inappropriate to the scale of the logistics of what we were doing. That was the thing that emerged.

Each crew member got a dive plan which was individually tailored to their vehicle in terms of the timeline and their activities—the individual objectives for each crew and the science activities as well. The science activities required a separate pre-dive meeting by the science group who would bring us their requests and recommendations for modifications to the sampling equipment on the front of the subs.

One of the things I would like to express here today is the idea that, regardless of how much you plan, you have to be willing to accept the idea of failure. I think that we are enthusiastic fans of exploration, probably everybody in the room, but failure is a part of exploration. It is absolutely woven into the fabric of the act of exploration. By definition, exploration means you're doing something that has never been done before. It is absurd to assume that activities without precedent can be done in complete safety. If only the remote and hostile environments are yet to be explored, then we are inherently pushing the limits of human endurance and technical adaptation every time we advance the boundary of what is known.

It is absolutely important to use all of our accumulated knowledge to be as safe as possible. However, safety is not the most important thing. I know this sounds like heresy, but it is a truth that must be embraced in order to do exploration. The most important thing is to actually go. Because if safety were the most important criterion, we would not go to Mars for 10,000 years, because only then could we assure absolute, 100 percent success. Historically the success of cultures and nations has been the result of their ability to balance risk and reward—to put it another way, caution and boldness.

The problem with exploration is not the individual's perception of risk; it's the institutional, national, and political perception of risk. Astronauts are smart people—I know a few of them. Most of them are Ph.D.s in one thing or another—engineering, physics, medicine. They know that riding a pointy end of a metal object that is screaming through the atmosphere at 20 times the speed of a rifle bullet, being propelled by one long continuous explosion is not quite the same as sitting at home in your Barcalounger.

They understand the dangers. They get it. They have assessed the risk. But their personal dream, their vision—not for themselves, but for the entire

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human race—dwarfs that risk. They know the importance of what they are doing, because in their souls they are explorers. It's not the astronauts who are going to hold up the progress of exploration. It's the government that funds them, and the people that empower that government to act, who will set the limitations. Institutions gravitate inexorably toward a value system in which any risk becomes unacceptable, at which point exploration ceases.

Now, we are lucky right now to be on a cusp with history where a presidential mandate has put NASA back on track with a renewed vision for exploration. NASA has reorganized around the guiding principle of exploration beyond Earth's orbit. This is all very exciting, it is all very new, and it is definitely happening. I believe it is a wise plan, and an affordable and achievable plan.

But there is one huge challenge that still needs to be overcome, even if we deal with all of these short-term reorganization issues. We must overcome the fear of failure that may inhibit future leaders from allowing these missions to proceed. The challenge will be this: the only way to fail in landing humans on Mars is to actually go. If we study the problem, we build tools and systems and so on for the next 50 years, we can kind of jolly ourselves along that we are really, honest-to-God going to do it someday, that we're still those clever Americans who put a man on the Moon back—when was that again?

That way we don't put our self-image at risk. But the second the button gets pushed and we are really going, then we enter a much higher realm of risk.

"Failure is not an option" was a good credo for getting the Apollo 13 astronauts back home safely, but as a driving principle, it doesn't really work. Failure must always be an option, or we stop being an exploring species.

When I started our most recent expedition project, I called a big summit meeting of all the department heads. I stood in front of a white board and put up on the white board three slogans. The slogans were there: "Luck is not a factor," "Hope is not a strategy," "Fear is not an option." Now, the first two were meant to convey my philosophy that to succeed in any complex task, it is essential to leave nothing to chance. You need to make your own luck by rigorous application of a robust process. You test everything in a very disciplined fashion, you don't guess, you know the answer, you anticipate every negative condition that might possibly prevail. You assume it is going to happen. You have an A plan, a B plan, a C plan, and you assume that you're going to be on the C plan by your second cup on coffee on morning one of the expedition, because that's how it goes when you're at sea.

I wanted to scare them, and I wanted them to respect their adversary—not the ocean, but the real adversary: entropy, which, as you know, is the tendency of things to go from a state of organization to a state of chaos.

The third slogan, "Fear is not an option," was meant to inspire the boldness that actually sees you through these endeavors. It was the yin and the yang of the healthy paranoia which the first two slogans represented, because without a kind of faith, which is not in luck and not in passive hope, but in yourself and your team and in the greater meaning of what you're setting out to do, you won't find the strength to go through with it.

So my message is, in whichever realm, be it going into space or going into the deep sea, you have to balance the yin and yang of caution and boldness, risk aversion and risk taking, fear and fearlessness. No great accomplishment takes place, whether it be a movie or a deep ocean expedition or a space mission, without a kind of dynamic equipoise between the two. Luck is not a factor. Hope is not a strategy. Fear is not an option.

NASA Image/Renee Bouchard

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Over the Edge of the World

Ferdinand Magellan took almost three years to circumnavigate the globe. In fact, he didn't make it. He was killed in the middle. Jules Verne wrote about going around the world in 80 days. I am going to take you around the world in Magellan's tracks in about 10 minutes, much more safely than Magellan did. In terms of risk and reward evaluation, keep in mind that, of the approximately 260 sailors in five very small ships that he took, leaving from Seville, Spain in 1519, only one ship with 18 sailors made it back three years later to Seville. One ship mutinied in the Strait of Magellan and returned early. Over 200 hundred sailors died in this attempt to circumnavigate the globe. That was not exceptional.

In this era of exploration, in the 16th century, it was a different mind-set. The very rational and logical and useful tools for evaluating risks and rewards didn't exist. The mind-set was closer to the medieval mind-set, even though this was the quintessential Renaissance exploration mission more than anything else. We can see, despite that mind-set, modern tools and paradigms and approaches emerging. Nevertheless, people went with an expectation that if they succeeded, it would be God's will, and if they failed, that was God's will. That was Magellan's inspiration for going, and that turned out to be, as you'll

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OPENING PHOTO:
The Strait of Magellan in winter viewed from NASA's SeaWiFS satellite. (Source: *http://visibleearth.nasa.gov*. Search for 9251.)

see when I get to the part about Magellan's death, his undoing as well, despite his many crew members urging him to ignore what he felt was God's will.

His mission to circumnavigate the globe for the first time ever was not meant to be a scientific one. That concept really didn't exist. He was going for two reasons, and they were pretty basic reasons. One was for greed, and one was for glory.

There were two superpowers in those days, one of the important analogies to the recent present, during the Cold War. Those superpowers were Spain and Portugal, and they were vying for control of the ocean. They were doing that because they were vying for control of the world economy, or the global economy, such as it was. The key to that economy in those days wasn't oil, the way it is now; it was spices. We all say, "What's the big deal about spices—cloves, cinnamon, nutmeg? Who cares? You can buy them in the supermarket." In those days, cloves were the most valuable commodity on the face of the Earth. They were more precious, pound for pound, than gold.

On his voyage, Magellan refused a number of opportunities to trade iron for gold on a pound for pound basis, because he wanted to save space on his ship for the cloves, which were more valuable. That one surviving small ship, less than 90 feet in length, *Victoria*, that made it back to Seville laden with cloves, made enough money for the bankers who financed it and for King Charles, the Spanish banker, to make the whole expedition—which was, in human terms, a tremendous disaster—a huge commercial success. This inspired Spain to follow up five times, each time unsuccessfully, on Magellan's vision of circumnavigating the globe.

For me, researching this book, there are two approaches. One is the library. People often say, "Well, where did you go to research this book?" And I usually quickly deflate the balloon by saying, "To the library," because that was the most important place. However, the library really isn't enough. You really have to get out into the field. It always reminds me of when I was a kid and dropping those little paper Japanese flowers into water—just add water and they come to life.

When you go to the Strait of Magellan or you go to Sanlucar de Barrameda, the port city in Spain from which Magellan's ships left, you begin to see the scale and the scope of what it was like. When you walk across a life-size replica of one of Magellan's ships and see how tiny it was and how primitive it was, you realize that what they were taking looks to us, on a temporary risk-reward evaluation basis, to be doomed to failure. But they didn't think that in those days. They thought that God was going to be on their side. And I'll try and explain a little bit to you why.

So for me, this was mostly tourism, to go in Magellan's tracks. Someday, to go in the tracks of Neil Armstrong or Jim Lovell will be mostly tourism. Not yet. And it [would have] seemed inconceivable 500 years ago that tourists would go through the Strait of Magellan the way I did, with a couple of friends with our cameras, walking over glaciers that [had] imperiled Magellan's life and the lives of all his sailors. And the glory part of this was that they were going to bring Christianity and the glory of King Charles—who was all of 18 years old when he commissioned Magellan to go on this voyage—around the world and spread those two goals far and wide as they went to claim the Spice Islands, which are in Indonesia, for Spain. Nobody really knew exactly where they were, and part of the expedition would be to find a shortcut, a fabled route somewhere through the South American landmasses to the Spice Islands. The exact size and shape of South America was not really known. Something was known about the eastern coast and that was all. They would cross what was known as the Pacific Gulf, considered to be a very small body of water.

My book on Magellan actually began on Mars with my previous book, *Voyage to Mars*, which was about NASA's robotic exploration of the red planet through four missions, from Pathfinder through the ill-fated Mars Polar Lander. During that time, NASA scientists at Goddard and JPL [Jet Propulsion Laboratory] kept talking about precedents for their exploration of the universe. They kept talking about Columbus; we all know a lot about Columbus. They talked about Balboa. They talked about Vasco da Gama and they talked about Magellan. And, after about the tenth or maybe the twentieth time, the name Ferdinand Magellan

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was mentioned to me, a dim light bulb eventually illuminated in my mind, and I thought that might be a very interesting idea for a book. It might have a lot to say about our own current age of exploration of the solar system and the universe. Because after all, at the time that this man, Ferdinand Magellan, went around the world, the world was as mysterious to Europeans as the solar system and the universe is to us.

Who was Magellan? First of all, he was a misfit. If he was on this panel today, he probably would be the least popular member. He would be the one that everybody would be looking at and saying, "He looks like a fanatic. He looks like a weirdo." He wouldn't have that genial, easy-going manner and that self-deprecatory humor that we admire in pilots and captains who are undertaking high-risk missions. From the little bit that we know from contemporary observation, he had a knack for being abrasive and for offending people. He defected from Portugal, because he couldn't get backing from the king of Portugal, who personally disliked him, to Spain, where he really wasn't a known quantity. He was preceded by a reputation as a daredevil, Portuguese soldier and a mariner, but he was an unknown quantity. And he quickly managed, through some sleight of hand, to get backing from the king of Spain and his backers, who were older and wiser, because they were desperate to beat Portugal to the Spice Islands, much as this country was desperate to beat the Soviet Union to the Moon during the height of the space race.

Magellan was limited by his communication skills—he never learned Spanish well. He was very embarrassed by his heavy Portuguese accent. He usually communicated through very stiff documents. If he ever cracked a joke in his life, there was no record of it.

But he was an obsessive personality and two things obsessed him. [One thing was] navigation, and he was a perfectionist in navigation. And as a Portuguese, he was aware of what was then the state-of-the-art of navigation and cartography in the world. Portuguese were like the Soviets in the space race, obsessively secretive about their cartography. If you published a book in Portugal that contained any map or information about Portuguese voyages, you were thrown into prison. And, of course, the book was destroyed. This was, of course, after the age of Gutenberg and [the publication of] Columbus's books had been a very important way of disseminating information. In fact, Columbus was Magellan's boyhood hero, and when Magellan read Columbus' account of his first voyage to the new world, that inspired him to go even further than Columbus, the way some astronauts today are inspired by their childhood memories of watching John Glenn and other astronauts, and their exploits, on television.

So Magellan, putting it mildly, was not a people person, but he was a brilliant navigator. He was also obsessed with one other element of his fleet of five ships, which were all leased and were all in bad condition: food. Most of the records that we have of that time—and they are voluminous—show that he was exceedingly careful about provisions and feeding the men what he thought would be the most effective diet. And tremendous thought and care was given to the kind of food, even though it was all horrible food, it was all salty. It was salt beef, it was salt cod, it was salt pork, there were olives. The only sweet thing was honey, which was taken along, and there was a tremendous amount of wine, which was the staple beverage. It was mixed with water, so it probably wasn't very tasty. And the other staple element was hardtack, that was basically stale biscuits. It was a month old by the time it even got on the ships, and it gradually became wormy and rotten and soggy as the voyage went on. And even when it was soaked with the feces and urine of the rats which infested the ships, the sailors continued to eat it because there was nothing else to eat beyond their rations, except for the leather wrapping the masts of some of the ships.

You may wonder why anybody would want to go on a voyage like this. In fact, most of the sailors came from the convict or semiconvict class and had no other hope for their survival in Spain but this voyage of escape from whatever their current problem was. Perhaps it was marital problems, perhaps it was debts, perhaps it was some crime that they had been accused of and this was their one escape. The officers were motivated often by greed because, after all, if they could bring or smuggle back some of these cloves, they would be set for life. Even a sack full would be enough for them to purchase a small house in the sailor's suburb of Seville and live there comfortably for the rest of their lives.

Magellan went because he believed that he was going to discover a new world. He really was impelled by what we would call idealistic motives. Now, the king of Spain gave him tremendous latitude. He was given the ability to name continents and islands after himself, none of which he did; in fact, he turned out to be very self-effacing. The Strait of Magellan, for example, he named the Cape of the Feast of the 11,000 Virgins, which doesn't really roll off the tongue that well, because that was the feast day on which he discovered it. So he was giving primarily religious names to places he discovered because he was a very devout individual.

His crewmembers came from at least ten countries. They spoke at least ten languages, and they didn't get along. They consisted of a number of cabals, and the Spaniards didn't talk to the Portuguese, who didn't talk to the English, who didn't talk to the Germans, who didn't talk to the Norwegians, who didn't talk to the Greeks. You may wonder how they communicated just to get ordinary sailing and nautical tasks done. They used an argot that was a Catalan slang that they all understood. But there was no easy rapport among these crewmembers, who would just as soon get into fights with each other as cooperate on their missions.

I think it's fair to say that Magellan, with his lack of so-called "people skills," faced much greater obstacles from the individuals on board the ship and the people he encountered in their travels around the world than he did from natural obstacles. In fact, he learned to master most of the incredibly overwhelming natural obstacles, including terrible storms in traversing the Strait of Magellan, which is a nautical nightmare. But he never really knew how to handle people, except with the most brutal means imaginable, such as torture, in order to inspire and put dread in the men to follow him.

The major player at that time was King Charles the V, the king of Spain and the emperor of the Holy Roman Empire. The king of Spain was a Hapsburg king; you can tell that by that famous Hapsburg jaw in the portrait of him by Titian. And it was in the name of King Charles that Magellan went. Keep in mind King Charles was an 18-year-old boy; he was trying to grow a beard when he sent Magellan on this mission, and even when the survivors came back three years later, he was only 21 years old and widely mistrusted by everyone around him.

The other major player in that era was Pope Leo X, who, as reflected in the portrait by Rafael, was a worried man. And if those Cardinals that are around him look like they are menacing him, it's because, in those days, the Cardinals were routinely plotting to kill and poison and strangle each other, and there were constant plots against the life of the Pope. Nevertheless, Magellan went around the world constantly pledging his loyalty and his entire expedition to the greater glory of the Roman Catholic Church and bringing the Church enlightenment to people around the world.

Magellan did not bring slaves or try to enslave people, which was a big difference between him and his boyhood hero Columbus. He did bring one personal slave with him, but when he found the so-called heathen in places, his first thought was not like Columbus's, "Aha! There are so many people here we can enslave!" His first thought was, "Aha! There are so many people here that we can baptize." Also, the group aboard included men, women, and children. So this already marked a very important shift from the previous era of exploration.

The maps they used at that time were worse than useless. The so-called "T&O map," based on a literal interpretation of the Bible, shows the ocean circling the world, only three continents, Jerusalem at the top—it was absolutely useless for anything. And this was the way most people—although not scholars—looked at the world at the time [of] Magellan['s travels]. This would be circa 1515.

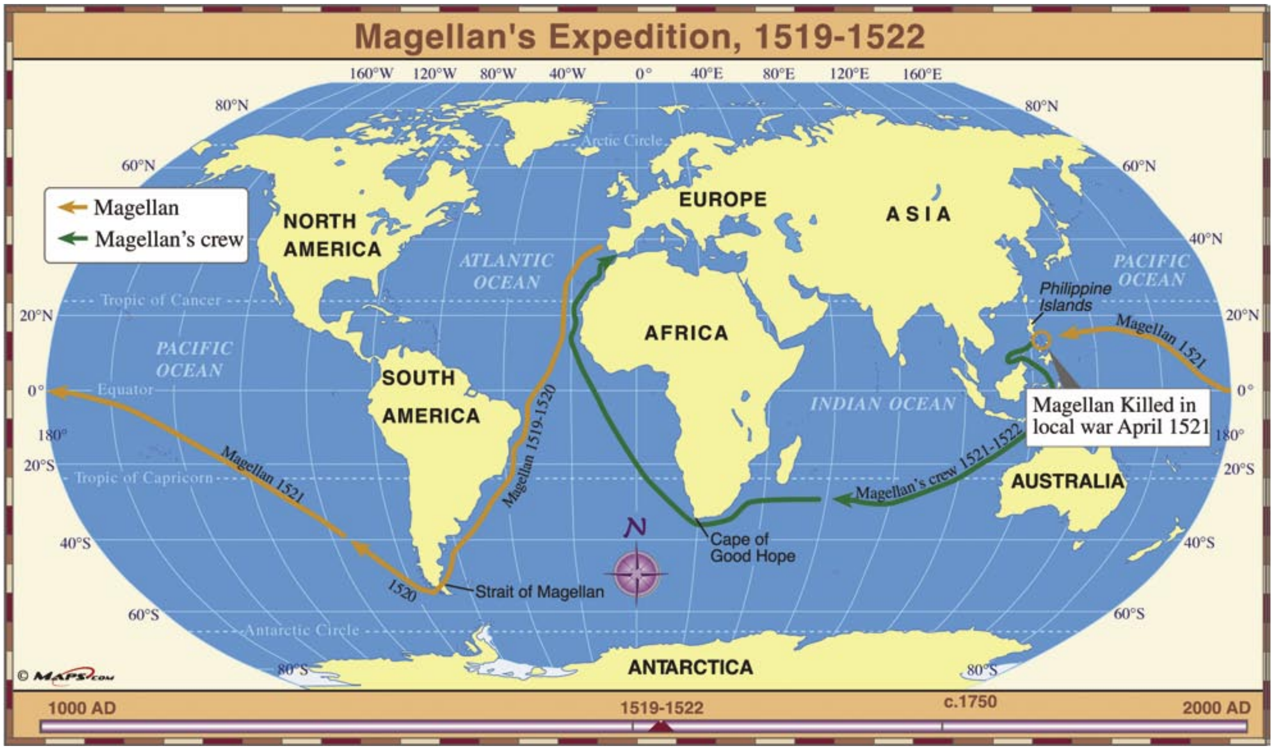
There was a state-of-the-art map that was based on the calculations of Ptolemy, the famous Greek-Egyptian mathematician whose mathematical compilations were rediscovered and published during the Renaissance. The map is a projection of the world as a sphere, based on his calculations. The one dramatic omission is the Pacific Ocean—9,000 miles! Had Magellan known that after he accomplished his greatest feat of navigating the Strait of Magellan, which is at the southernmost tip of South America, that he still had to cross the Pacific, he probably wouldn't have gone and he probably wouldn't have gotten backing from the Spanish crown or from the financiers who were expecting—like businessmen everywhere—a reward, a return on their investment. They were hoping for about 14 percent, incidentally. So his maps were mostly useless. In fact, when he got to the Pacific Ocean, he was so exasperated with these kinds of maps and charts that he threw them overboard in a temper tantrum and said, "These maps are not to be trusted." And from then on, he relied solely on his own charts.

A map of his actual route gives you an idea of how it looked in the world as it actually was. And you can see his route as he leaves Seville and goes to the coast of South America following a well-worn path by that point, until he begins to work his way down to near the southernmost tip, looking for the Strait of Magellan, which he had promised his backers and the king of Spain he'd find or else. And, finally, he did manage to find it. But from then on, for most of his route and for most of those three years, he was sailing through waters that were uncharted by European cartographers and so were unknown to him.

We don't have an image of his actual vessel. But we know it rides very high in the water. It's dark brown or black because of the pitch, the tar covering the sides to keep it seaworthy. Depictions of ships of the time are shown surrounded by flying fish, which were a constant fact of life of some of the earlier parts of the voyage, and by some sort of sea monsters, which were believed to exist.

Some of the hazards that they believed to exist at that time were mermaids, considered to be a fact. Another was a magnetic island; if the ship sailed too close, the island would pull all the nails out of the ship, the planks would come apart, end of story. That was also considered to be scientific, factual. Then there was the mythical continent of Terra Australis. Not until the 19th century was the existence of this continent, thought to somehow counterbalance the continents of the Northern Hemisphere, disproved. And, also, the water was thought to boil at the equator, because it would be so hot.

So, there were all sorts of imaginary hazards that Magellan and his sailors thought they were facing, which turned out not to be the case. However, they



Ferdinand Magellan's route around the world (1519–22). (©1996 MAGELLAN Geographix™)

were also facing real hazards that were in some ways even more dangerous. For example, scurvy. Scurvy was the radiation poisoning of its era. There was no known cure for scurvy. We now know that a teaspoon or less of Vitamin C taken a day, in orange juice, or many herbs, or even beer, or malt, is the magic bullet cure for scurvy. But Europeans didn't know about that until 200 years after Magellan's voyage, which was a complicated, fascinating medical story in itself. At that time, scurvy was a dread disease. It caused loosening of the teeth and mottled skin, and then, literally, the hard parts of your body, your bones, your teeth, your tendons, would come apart—your body literally falling apart. And over thirty sailors on Magellan's crew succumbed to the deprivations of scurvy and a horrible death at sea because of this disease, which we now know is so simple to prevent.

So, danger was everywhere, and again, prayer and a belief in the divine will was about the only protection that the men felt they had against it.

One of the great false leads of the voyage was the Rio de la Plata, South America, which many of the men insisted was actually the Strait of Magellan. Of course, it's many hundreds of miles north. When Magellan saw it was shallow and covered with silt, he figured, just based on sheer instinct, that it wasn't deep enough to somehow cut through the South American land mass, and come out the other side in the Pacific Ocean. And so he sailed around the bay, and kept going, and said, "This is not it." The men didn't agree, and they mutinied, and he responded to the mutiny by drawing and quartering some of the leaders, which was a brutal procedure that involved removing their intestines while they were alive, burning them in front of them, and, eventually, decapitating them, putting their heads on a stake, and putting those stakes in the harbor where the ships were moored in order to enforce discipline. And that was how Magellan kept his men in line. It was a very, very different era from today, as I was saying at the outset.

One of his chief discoveries, which was truly accidental, was the Magellanic Clouds. Now, as I mentioned before, this was not a scientific mission. Not until the Age of Enlightenment and Captain Cook in the 18th century was the concept of a science mission really popular or prevalent. Nevertheless, Magellan brought with him a chronicler who had never been to sea named, Antonio Pigafetta, a funny name. But Pigafetta was a rather intelligent, very ambitious young Venetian diplomat who heard about Magellan's voyage when he had gone to Seville, and he signed up for this mission. And most of the important things we know about it comes from the diary that Pigafetta kept on the voyage. He survived, and Magellan didn't.

These Magellanic Clouds, which were until about 10 years ago thought to be the galaxies closest to the earth, were simply described by Pigafetta as two "clouds of mist." Period. They had really very little idea of what they were looking at, but he noticed everything. He also wrote down 30 different languages that Europeans didn't know about, spoken by various preliterate tribes around the world, giving us our first lexicographies of all these languages. So he was an astronomer, an ethnographer, and an anthropologist. He also became, because he learned these languages, translator for this mission. Pigafetta turned out to be one of Magellan's best hires, let's put it that way. Especially because he survived.

The Strait of Magellan itself is unchanged from 500 years ago. It's basically a fjord. The water is very cold. If any of the sailors had fallen overboard, they would have survived six minutes at most. By the way, most of the sailors then didn't know how to swim, and they had a terrible phobia about the water.

Five hundred years later we walked across what our guides like to call a "cold beach." There were Magellanic penguins, which were ubiquitous [and] which bailed Magellan's sailors out of starvation time and again when they went through 500 years ago.

The way Magellan managed to navigate what was really a maritime maze—not a straight watery path—was to have his men climb mountains, and look ahead and see, well, which way to go. What was a dead end, and what was going to take them to the Pacific during this 300-mile crossing? He also tasted the seawater. When it was salty, he knew he was near the Atlantic. When it got to be fresher, he figured he must be getting to the middle of the strait. And when it turned salty again, he figured he must be coming out to the Pacific, which was a misnomer, because the water there was even rougher than it had been in the Atlantic, where he had faced some terrible storms.

Glaciers were noted by Pigafetta, and looked at by all the men, but they couldn't figure out why they were blue. Of course, they're blue for the same reason that water is blue, because of the way the eye selectively absorbs scattered light. Magellan's fleet was very lucky not to have been crushed in one of the glaciers.

Magellan very unwisely immersed himself in a tribal war when he reached the Philippine Islands. When he reached that archipelago, he was actually worshipped, literally, by the islanders there, whom he converted to Christianity in mass baptism, including men, women, and the children. Pigafetta calculated several thousand conversions. And Magellan got so caught up in this that he wanted to keep on doing it. Meanwhile, all his officers who had survived to this point said, basically, "You know, we're on a commercial mission here. We have to get to the Spice Islands. You don't know where they are. We've got to get there." But Magellan said he wanted to stay.

There was one island leader we know by the name of Lapu-Lapu, who was in a war with all the other islands in the Philippines. He was the ruler of the island of Mactan. And he decided that since all the others were converting to this new and strange deity who was brought from afar in these gigantic black ships, he was going to do the opposite. So, he challenged Magellan to a battle. Magellan, as you might gather, was never one to back down from a fight. And he said "Fine, we'll undertake this battle." He figured he had gunpowder and weapons, guns on his side, which were very primitive and as likely to blow up as to fire correctly. But they did have crossbows, which were far more lethal, and they also had armor. Magellan figured that armor would be impervious to blows from bamboo swords and that one of his soldiers would be able to defeat 50 or even 100 island warriors.

So Lapu-Lapu challenged him to a battle. Magellan decided that 60 men would be enough for him to handle whatever Lapu-Lapu threw at him. He waved off assistance from a local sultan who offered all of his soldiers and troops to Magellan in favor of Magellan's support. He waved off offers of support from all his men. He told his ships to stay way back—he didn't need to be covered by fire because God was going to protect him.

So, he undertook this amphibious landing early in the day on April 27, 1521. His 60 men were met by 1,500 enraged soldiers with fire-hardened, poison-tipped swords and with bamboo shields who charged into the water and eventually overwhelmed Magellan, once they figured out who Magellan was—and he was rather conspicuous because of his plumed conquistador's helmet. (Note to other explorers, don't wear a conquistador's helmet while fighting the enemy!) They managed to throw spears at the exposed parts of his body, at his arms and his legs. Finally, they managed to knock his sword out of his right hand. When he stooped to pick it up from the water, he took another spear in his arm, disabling it. And then Lapu-Lapu's soldiers closed in for the kill. And, essentially, they hacked Magellan to pieces right there in Mactan harbor, and there was nothing large enough left for even a proper burial. And that was the death, the very, very unnecessary death of perhaps the greatest explorer of the entire Renaissance era.

His crew had seen this coming, because they had been aware of his growing recklessness, and they quickly elected two captains, Portuguese and Spanish, to continue the expedition all the way to the Spice Islands. And then, finally, overcoming one disaster after another, one ship made it back.

By the way, the one ship that made it back was captained by a Basque mariner, Juan Sebastián Elcano. And in Spain this is known as the Elcano mission, rather than the Magellan mission, out of a nationalistic feeling, because Magellan was Portuguese and was viewed with so much suspicion by the Spanish authorities.

So, as you can see, the idea of what exploring was like in those days was almost incomprehensible compared to what we're used to today. And so our exploration of the solar system continues in that spirit, but with a tremendously different approach from what it was like then. ■

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Discussion

DAVID LONGNECKER: My name is David Longnecker, from the University of Pennsylvania, and I'm addressing my question to Mike Gernhardt. I was intrigued by your calculation of acceptable risk for DCS (decompression sickness). As you know, the concept of acceptable risk is one that's getting considerable play throughout NASA, as we look towards future exploration. Do you think it's possible to apply such techniques and such mathematical approaches to broader risk categories, as we look for broader missions?

MICHAEL GERNHARDT: That's a great question, and the answer is: absolutely, you can. There are limitations, obviously, to the data and to the statistics, and, ultimately, you will have to make judgments. I found that running this process, I started out with an uninformed group and my own notions of what acceptable risk were. And we ended up with an educated group and a specific definition and a consensus to move forward. So, I think the answer to that question is yes, a similar process could be run with return to flight, using models that are out there for [foam-shedding] and MMOD (Micrometeoroid/Orbital Debris) prospectively defining what acceptable risk is for reentry. The only danger is that that should not be a substitute for good judgments. And I think if you look at that as one tool, a decision support tool, it could be very valuable in that regard.

EUGENE RODDENBERRY: Hello. Eugene Roddenberry. Actually, I've got a question for Mr. Cousteau. I wonder if you could tell us about what your son is doing today and if he's okay. From what I hear, speaking about risk, he's taking some risk right now.

JEAN-MICHEL COUSTEAU: Well, I think he's taking a very calculated risk. He, and some of the Hollywood people have helped him, built—that was a dream of his for a long time—a life-size great white shark in which he's hiding. The structure of the great white, which can move on its own, is such that anything can attack it and he's completely safe. What can go wrong is his life support system if he doesn't do the right thing. So, it comes back to him. It's not nature that's the problem, it's human.

His objective is to find himself in the middle of other great white sharks, perfectly protected, a lot better than I was when I was in South Africa. And he, from the inside, can see through the eyes of the shark, as can the cameras which are looking out through the

OPENING PHOTO:
Backdropped against the blue and white Earth 130 nautical miles below, astronaut Mark C. Lee tests the new Simplified Aid for EVA Rescue (SAFER) system.
(NASA Image Number STS064-217-008).

eyes, at what's going on around it, and can kind of study the behavior of these sharks, which we know so very little about. So, from a scientific point of view, hopefully, they will make some new discoveries as to the behavior of great whites by including less risk than if we were in cages or even scuba diving. So, I don't think he's taking a lot of risk, personally. Much less than other people have, and, hopefully, we will learn something. And that's what he's doing at the moment, as we speak.

DAVID LAWRENCE: David Lawrence for Laurence Bergreen. Was going around the world the great challenge in 1519 that Magellan hoped to meet, or was it just to get the cloves and get home, and it was just accidental that his expedition continued to make the first circumnavigation?

LAURENCE BERGREEN: Yes, that's a good question. The latter. It was almost incidental. He figured that was the fastest way to get to the Spice Islands to bring home the spices and to avoid the time-honored overland route, which was much slower, far more expensive, and controlled by the Arabs. So, it was really what he felt was the expedient way to do it. The efficient way to do it.

GORDON OSINSKI: Gordon Osinski, from the University of Arizona and soon moving to the Canadian Space Agency. We've talked so much, so far, about the risk of exploration, and the title of the symposium, but until this morning, nothing about the risk of not exploring. I think John Chatterton said, "Exploration is who we are. We should continue on the path of exploration or quit." And Sylvia Earle said, "Something is happening to us as a species." There are people yesterday who thought, to continue evolving as a species we should explore, we have to explore.

I was moved by the reasons why we should explore the sea, and we're looking to the stars. I was born a few years after man last walked on the Moon. I've been doing some teaching recently and I'm shocked, aghast, at how many people think we have not walked on the Moon, or actually, how many people think we have walked on Mars. So my question is: Is there a greater risk of not exploring than exploring? And maybe pose that to the whole panel and to everyone.

JEAN-MICHEL COUSTEAU: I would just like to jump in by saying that we've done a very, very poor job of communicating the results of our exploration to the public. I mean, you'd be amazed to go in parts of the country and find out that people don't know anything about what's going on at NASA. And we have to see a communication resolution, that we are leaving at the moment and taking for granted. We have to find a way to get, particularly, young people to know what's going on. And by doing so, we're going to revive the excitement of exploration and stop, once and for all, this concept that everything has been done, and everything has been discovered, and there is nothing to do, and let's go and have a drink. It's very, very sad, and I see this more and more. But there are people who are starting to make a difference in that sense. So, we need to really tackle young people in schools.

SYLVIA EARLE: If I could jump in on this. I was so dismayed by this cover story on a new magazine, I think it was *U.S. News and World Report* last spring, about the great age of exploration being over. That the great frontiers were during the time of Magellan and Columbus and all that. And yes, there's much to be done out in space, but this planet is largely explored. I actually sat in an Explorer's Club banquet one evening and listened to a spokesperson for space exploration talk about how the only frontiers left were up in the sky, until Kathy Sullivan kicked the speaker from under the table, and I got up and gave him a laser look from across the room. We're talking Carl Sagan here.

And he backtracked and said, "Oh, yes, most of the ocean has yet to really be explored." And that's the point, you know? If I were in charge, the administrator of an agency with the objective of looking at the solar system and surveying all the planets and all the things and even beyond, I'd say, "That blue one! That one there with all the water. That's the one we really need to concentrate on because that's where the action is!" If you're looking for life, find the water. And we've got it. It's here.

And my greatest fear is that we, with all of our technology and knowledge about how dependent we are on the natural systems that support us, we're going to let the system degrade to the point where our species is going to be in trouble. We are in trouble! The thing is, we don't appreciate it. I'm all for looking skyward and in every direction of exploration, but it baffles me why we aren't really motivated to look inwards. To look at the ocean, to explore it, and to find a place for ourselves here within the natural systems that sustain us. And to apply this great technology that we have to really understand the magnitude of what we don't know about the ocean, and put it to work for us, for our survival, for our well-being. This is the time.

In the next ten years, if we don't really take action, we're going to lose the chance with many of the species that we have taken for granted all our lives—tuna, swordfish, and the like. It's going to be gone! Coral reefs and all these other systems that are at risk right now. We have the capacity to turn things around. The real question is, are we going to use our knowledge in the spirit of exploration to do it? I mean, Goethe said, "It's not enough just to know. You must act." Well, we know. Do we have the capacity now to act?

JOHN CHATTERTON: The spirit of exploration is certainly one thing. But exploring requires resources. It requires money. And right now, we're very much satisfied with spending money on weapons of war, on SUVs, on things that are really counterproductive to our best interests. And, certainly, one of those things would be exploration.

JAMES CAMERON: Well, I think that's an excellent point, you know. I guess I tried to make it—probably crudely—that the type of exploration that remains to be done on our planet requires more advanced technology than previously. You could do a lot and put your names in the history books with a small ship—which was state-of-the-art at the time—or some sled dogs and some true grit and some luck. These days, none of those things are sufficient. You need large organizations like NASA or NOAA, Wood's Hole [Oceanographic Institution] or MBARI [Monterey Bay Aquarium Research Institute] or some body like that to provide technology and support staff and engineering and so on, so it does boil down to a budget issue.

Go back to Mike's formula, you know? Cost is a factor, the likelihood of success is a factor. You run that equation. That applies to the financing [of] a movie, the funding of a deep-ocean expedition, or an entire research program that might deal with the deep. People look at it and say, "What's the reward? What's in it for me?" But there are new and interesting ways to finance explorations that didn't exist before. The deep ocean is revealing such vast biodiversity that whole new genomes are being revealed, and there are pharmaceutical companies that are interested in bioprospecting the deep ocean, which will allow them to create new drugs, new treatments, and so on. So there's renewed interest in pure exploration, in a sense, and biosampling in realms that previously were being overlooked as not economically viable.

So it's just a question of being creative about how we create the funding paradigms. I've tried to do something a little bit unusual. In the past, filmmakers have piggybacked on scientific expeditions that were going anyway for reasons of the goals of their various parent institutions. We flipped it around on our last film and got the money from the media sources, then went to the scientific community and said, "Hey, we're going out with submersibles to the hydrothermal vents in the East Pacific Rise and the Mid-Atlantic Ridge. Who wants to come along and take advantage of these assets that we're marshaling out there for imaging purposes?"

And interestingly, our best response was from the astrobiology community. We wound up taking researchers from Ames and Johnson Space Center and from Jet Propulsion Laboratory with us out there to—not to do analogue research, but to look at the biology of the deep vents and relate it to what they might find in the fossil record on Mars or other places in the solar system and beyond. So we were actually using media and entertainment funding to help with science and exploration. There are different ways to skin the cat, but I think the important thing is for everyone collectively to try to engender the passion for exploration in the next generation.

And part of that is reminding them of the heroes of the past and keeping that image alive, and part of that is reminding them that there is so much of the world and of the universe that has yet to be explored. It is within our grasp, and it's a real adventure that we can really have and really enjoy in our lifetimes, if we put our will toward doing that.

SYLVIA EARLE: What is the cost of not exploring? That's the real factor.

ANDY PRESBY: My name is Andy Presby. I'm a student here at the school. When a person of my meager accomplishments attempts to suggest something that may be new to a group such as this, he must do so with a certain degree of humility.

I hope you will recognize the respect that I have for everyone in this room and everyone, particularly, at that table. I think you guys are missing the point.

I've heard a lot of talk over the last couple of days, and I've been a space nut since I was three years old and my daddy took me to see one of Mr. Roddenberry's movies. However, we talk a lot about the scientific benefit. We talk a lot about the personal exploratory benefit. For example, exploring Mount Everest. You then go and talk about the need to inspire the next generation of explorers, and I completely agree with you, Mr. Cameron, that that is absolutely required. You've talked about the cost. We talked yesterday about a goal, and typically, when I hear somebody in the space community talk about a goal, they mean a planet. They mean a body. I don't think that's the goal that will inspire that [next] generation of explorers.

We have for the first time in human history come to recognize that, as you say, Mr. Lovell, we are living on a spacecraft, a giant spacecraft that we didn't design and we don't know how it works. Now we're screwing around with the life support mechanisms. I work in submarines. I understand and fully appreciate the need to keep life support gear running, but I also understand the need to explore the environment around me and, perhaps, find alternative means through which the needs of—what is it now?—six and a half billion people who all want the American standard of living, which, if I am not mistaken, involves approximately two personal slaves worth of energy per year per person.

We live in an environment that's flooded with energy. Space is full of it. I hear folks talking about very narrow goals, and we're talking about scientific goals. We're talking about exploratory goals and personal goals, and those are all important. Those are all immediate short-term goals, but I argue that, to inspire the next generation of explorers, you need to speak about long-term goals such as finding ways to relieve the pressure that we place on our environment by looking at, and yes, it's going to be expensive, sir, ways of moving resource production and other systems such as that off planet.

I have a tremendous interest, and everyone sitting here in this row has a tremendous interest, in the sources of human conflict. The two sources of human conflict, as my friends have said, are the misunderstood "other," close proximity to same, and lack of resources. Why don't we speak about that?

DAVID HALPERN: Very well said by the next generation.

JAMES CAMERON: I wholeheartedly agree that energy is probably going to be the source of conflict. It is currently the source of conflict. It is going to continue to be the source of conflict, and there may be energy sources revealed, whether it is mining helium-3 on the Moon, doing off-planet fusion production, creating antimatter on the back side of the Moon where the earth is shielded, or whatever you want to do. I think these are good ideas. I think that the issue of solving the problems with our life support system here—which is something I personally am passionate about but didn't speak about today because, frankly, I knew my colleagues here would do it because I know them well—is a separate issue from exploration. I think that there are aspects of exploration that are survival requirements.

When Sylvia talks about the risk of not exploring, it's really the risk of not having the technical capability to explore. We build our muscles slowly to go out and do these things. We are still on an indefinite hold in low Earth orbit, building up the muscle to learn how to support human beings for long duration in order to be able to go further. We are relying on our robots now to be our precursors out there. We have to build up this capability, and, personally, I believe you do have to have goals to do that. You have to have a focusing element. It can't just be an abstract thing: Let's go out and solve our energy problems out in the universe. We won't solve them at the Moon. We'll solve them here, generating the technology that enables that exploration.

In my mind, I uncouple the abstract goal of exploration, which is to satisfy the human soul—yearning, understanding, all those things—from the hard core nuts and bolts activity of exploration, which has always spawned so much in the way of economic enhancement of this country and of the other developed countries, because we put so much energy into the technology required to do these difficult and exotic things. We will develop an improved nuclear power system. We will develop fusion power. We will develop some of these things, and the control systems for same, in the course of trying to get to Mars or do these high energy things that we have to do in order to explore the solar system. Our understanding of distant stars from orbiting next-generation space telescopes and so on may be the key turning the latch of figuring out how to have an unlimited power supply here on Earth that will replace oil, and give us another different excuse in the future for going to war. Right now, our excuse is oil.

SYLVIA EARLE: While we do look for alternatives to our current energy sources—and we should definitely do that—meanwhile, we can make better use of what we've already got: more efficient use of our current energy resources. It is not just in terms of oil, gas, and things of this nature; I mean in terms of food resources, too. Twenty million tons of wildlife extracted out of the ocean is simply thrown-away bycatch. More than 300 thousand marine mammals every year are destroyed in the process of catching fish. We are seeing the fish that we are taking just collapsing. You know we are too good at catching these things. We are hunter-gatherers, but we're armed with new technologies that our predecessors could not imagine. So, we need to put on the brakes and think about more effective use of the resources that are here. We couldn't support six billion people with wildlife from the land. Ed Wilson, Harvard biologist, says we've seen consumed "the large, the slow and the tasty from North America over 10 thousand years". It's only taken us 50 years with our new technologies to do the same thing with the ocean. We are very close to losing some of the creatures that we have thought infinitely able to rebound no matter [how many] we extracted from the ocean. Exploration, in terms of finding solutions to the very problem you have posed—how do we find the place for ourselves that is going to last, knowing that our numbers have increased three times in my lifetime, but the planet stays the same size? Our capacity to support us is currently being stretched. It's not just oil and gas. It's oxygen in the atmosphere. What are we doing to that part of the world, the ocean, that is generating most of the oxygen, absorbing much of the carbon dioxide? We're messing around with it. We need to know how it works. That means explore it, and then, take heed. Not just, yeah, we've got all this new information, but acting on what we are learning and doing it in a way that secures a place for ourselves so we can continue to explore as long as humankind survives.

ANDY PRESBY: I don't know if anybody else wants to comment, but I didn't mean to focus specifically on energy. It was an example, and one that we can all relate to. I don't know if that helps anybody respond to my question.

JIM GARVIN: Jim Garvin, NASA, Moon and Mars Chief Scientist. They're our resources. I think the tenet I'm hearing in response to this great question is that we have to separate exploration, as a catalytic tool to make things better, from the applied end game of exploration that we can document in history, from Magellan's search for cloves and in finding first orbit of Earth. How do we measure that? One of [the] things we are asked all the time is, what is the yield from these catalytic things? Whether they be to inspire, what are they? We use lots of terms, and I think this audience would be wonderful to try come up with those metrics. This young man says inspiration isn't enough. Okay. As we catalyze, what is? The one I always find easy, maybe because I'm simpleminded and not yet quantum-computing, is IT. Information technology. Why are we doing it better in some places? Many reasons. Smart people. Maybe that's an area we ought to look at as part of exploration to extend ourselves to think better and to use our resources better to better inspire. Anyway, that's my comment for the group.

JAMES CAMERON: I think there is an inspirational dividend to exploration. I think this is one of the primary reasons to do it. I think you have to ask yourself, why are the Chinese doing a space program that basically mirrors what we were doing thirty years ago? Why is it important to them now, as the fastest growing economy on the planet, to be doing it, to simply be reproducing an accomplishment that is already done? Because they know that the inspirational dividend within their own borders is going to be significant in inspiring kids to go into technical careers in math, engineering, and science. So, the value that they are getting out of it is much greater than what they are putting into it. They've done the math. They can't win that race any more.

I think we should ask ourselves, what are we losing by not exploring, in terms of the inspirational dividend to a younger generation? One of the biggest problems this country is going to be facing is the lack of "fresh outs" in engineering, math, and sciences in the next ten years or so. We've got some big problems to solve, and we're too far down the path as a technological species to go back to the garden and try to pretend none of this ever happened. We've got to get ourselves out. We've got to think ourselves out of it as a technological species. We have to continue to build those tools and that capability.

Certainly, with the vast amounts available for military procurement, you've got people working in math and science and so on making pretty good livings there.

Wouldn't you rather have an alternative to that, though, in space exploration where we can focus our minds, improve our IT capability, improve our control over energy systems, and, by the way, understand long-term regenerative life support systems? If we're going to go to Mars, the point is to stay there, not simply touch base and run back. We're going to have to learn how to live there with very, very finite resources.

The more we learn about closed loop ecosystems, the more we need to know about the big, closed loop ecosystem that we live in, and vice versa. One body of knowledge will feed the other. I think there is an awful lot to be gained societally for the investment that we are making in space exploration, and I would certainly like to see a proportionate amount spent on ocean exploration. I know Sylvia is enlightened in that she is one of the few people in the ocean community that doesn't constantly complain about those billions that NASA gets.

When they're fighting for tens of thousands or hundreds of thousand of dollars, she is enlightened enough to know that all knowledge improves us all and that exploration should be constantly going in both directions. I agree with that as well. I could talk for hours about the value of analogues, of ocean exploration, of space exploration . . . And how you could build muscle in both places . . .

JOHN CHATTERTON: The other thing is that exploration should not just inspire more exploration. Exploration should inspire additional exploration, but it should inspire us to think big, to work on problems like energy, to work on problems like the environment, to work on problems like population. Everything that we've got on our to do list as a species, we need to apply ourselves, if we're going to find solutions. We don't really have that much in the way of a choice.

JIM PAWELCZYK: My name is Jim Pawelczyk and I'm at Penn State University. James Cameron, you mentioned in your talk that we've already picked the low-hanging fruit with regard to exploration. All of you have spoken about inspiring the next generation of explorers. Do we need a different educational paradigm in order to make those things mesh? And if so, what do you think it looks like?

SYLVIA EARLE: I have three children and four grandsons. It disturbs me that we aren't getting this generation coming along—the kids—actually out doing things in good, wild places. In fact, our safety mechanisms in schools dictate against it. You go to Hawaii, kids aren't allowed to go get in the water as a part of their school activity—not above their ankles, anyway—because, you know, it's not safe. So whatever it takes, whether it's museums, aquariums, moms and dads, whoever, we need to take the responsibility for getting kids connected with the real world, the living world, the wild world. We're missing it in the rather structured form of education as it is currently being conducted, not just in this country, but most of the rest of the world where education systems are—really, I mean, it's important to learn the ABCs and the 1-2-3s, but we've also got to learn that we're a part of this greater system, and that's missing.

PAUL SPUDIS: Yes, Paul Spudis, Applied Physics Lab. I want to thank Andy for stimulating a really good conversation here, because I think he's nibbling around the edges of something. I've been listening to this for the last couple of days and I've heard a lot of interesting things. But I have two comments. First, in regard to this argument of spending money on weapons versus exploration, they're actually complimentary and, in fact, historically, the exploration is something we let the military do during peacetime. And all the great explorations of the Pacific weren't undertaken because they were interested in the natural history of Polynesia, they actually wanted good maps that they could use to retain British control of the seaways.

The second point I want to make is that I think that we've nibbled around the edges of the issue of why we do exploration. And I think there's three motivations to it, of which we've only discussed two. The first motivation was discussed yesterday, and that's sort of the personal gratification. You know, because it's there, I want to go, I'm curious, I want to know. The second motivation is societal and collective. It's, we explore to get strategic information, to inform ourselves so that we can make better guesses on how to do something else, whether it's to identify other resources or to develop a technology or something like that. But no one's talked about the third motivation. And that is exploration as a prelude to settlement. We explore because we want to go live there. And one of the really interesting things that we got out of Apollo is an appreciation for the fact that, sooner or later, life on this planet is doomed. We know this because we know that impacts occur, and we know that in the past they've come darned close to nearly completely sterilizing the Earth—wiping out almost 95 percent of all living species. So, ultimately, someday, somehow, that's going to happen here.

And one of the big motivations, I think, for exploring space, is to create additional reservoirs of human culture, so that if Earth is destroyed, or the biosphere is destroyed, there will be, the human race will survive. Now, that's a long-term thing, certainly isn't a part of going to the Moon or going to Mars. But doing that by going to these places, we're going to learn the skills we need to develop the ability to live off-planet. Does anyone have any comment on that?

PENNY BOSTON: Penny Boston, from New Mexico Tech. I've been thinking about another type of risk that we really haven't addressed yesterday and today. And it's really a risk to exploration. When I look at everybody here who's doing exploration, we're all relying more and more on ever greater degrees of technology. So that the point at which one can participate in this, the number of people becomes narrower and narrower. You have to be well-educated and you have to have access to resources. And I think back to the famous essay by C.P. Snow, in the middle of the last century, the two cultures where you see this increasing dichotomy between those who know and those who have, and those who do not know and do not have. And it seems that, unless we attend to that growing bridge in society, that ultimately threatens our future in terms of exploration. I see symptoms of that in these sort of vacuous reality shows that are on TV. As much as we may denigrate them [the reality TV shows], what it seems to me to indicate is that the vast majority of people are feeling more and more uncomfortable with their excessively cloistered and safe lives, and that, perhaps, this need to acquire risk is general throughout the population, even though people like us manifest it maybe more obviously. And so, this potential danger to all of our enterprise, whether it be ocean or land or space, seems to me a festering element that we need to address.

JAMES CAMERON: I think that's an excellent point. And my answer would relate to the previous question about education. You suggested that the problem is that the technology narrows the band of people that can actually participate. But, in fact, technology can also be an enabler for people everywhere to participate, through improvements in information technology. And, you know, theoretically, we're all wired up to one big human nervous system. So, if we have an avatar, whether it's robotic or human, out there somewhere at the bottom of the ocean or in space doing something that's interesting, there's no reason why we can't all look over its shoulder and participate. But it requires a will on the part of the people budgeting that operation to make sure that they put in as a line item, not just outreach in the sense of, "We're going to tell people what we're doing and show them some images," but participatory outreach in the sense that, "We're going to let you look over their shoulders. We're going to spend that extra two or three percent on a major mission to let people actually participate." And I know that the recent activities on Mars have done an absolutely stellar job in doing that, if it can be judged by the number of hits to the NASA Web site—I think it's up to 11 billion now or something like that. People are looking over the shoulder of those little rovers. And if we had human beings there right now doing microbiology—I know that's your field—or whatever, if we should get so lucky as to find some evidence of that on Mars, people would be able to participate in that. So I think the solution is always going to be there as a technical solution. It's a question of imagining it before the fact and incorporating it into what we're doing.

SYLVIA EARLE: Just endorsing your observation about the need to have risk. It's a kind of spice. Probably more valuable than cloves.

DAVID HALPERN: With that parting comment, I think it seems appropriate to bring this session to an end. I'd like to thank Administrator Sean O'Keefe and Ames Director Scott Hubbard for the wonderful facilities that we're in now. And I especially want to thank each of the panelists for their dedication and their wonderful comments and their inspiration for what we've been doing. And I'd like to thank, finally, the audience for the wonderful questions and wonderful attentiveness. And with that, I have one more thing. Those of you who are from the East Coast probably have never lived through an earthquake, but you just had a 5.9 earthquake about 120 miles off the coast. So this here session is memorable in many ways. Thank you again.

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