Continuing the Voyage: The Spirit of *Endeavour*

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Good evening. I am truly honored to have been invited to speak before this august group. The Royal Society has a long and distinguished history of supporting explorers and scientists; indeed, for centuries the Royal Society was the embodiment of science in western civilization. Yesterday, I had the honor of making a very special presentation of the Society's prestigious Copley Medal to Professor Stephen Hawking of Cambridge University. This medal, the world's oldest award for scientific achievement, flew aboard Space Shuttle *Discovery* on the STS-121 mission last summer, part of the personal effects of British-born astronaut Piers Sellers, as a gesture in honor of Professor Hawking.

I hope that next week Space Shuttle *Discovery* will roar back into space with the STS-116 mission to continue the assembly of the International Space Station. When it does fly, another British-born astronaut, Cambridge graduate Nick Patrick, will be aboard. The upcoming Shuttle missions to finish the Space Station are among the most difficult and complex ever undertaken. On this mission alone, the crew will add another segment to the ISS truss, the backbone of the configuration. They will re-configure the electrical power system to incorporate and use the new solar arrays brought up on the last flight, and they will fill and activate the ammonia cooling system for two of the truss segments. The exploration and development of the space frontier is, truly, the most technically challenging endeavor of our generation and many to follow. But in carrying it forward, we are building on the heroic exploits of our forbears in their own missions of human exploration and scientific discovery.

I have no greater personal hero than former British Prime Minister Winston Churchill, a man whose distinguished paternal ancestors served Britain for centuries, yet who was born of an American mother. Throughout my life I have admired Churchill's famed incisive wit, his stunning oratorical skills, his steadfastness in support of that in which he believed, and above all the unbreakable rock of his courage. During the darkest days of World War II, as he sought to bolster his countrymen and those everywhere who fought for freedom, Churchill exclaimed, "We have not journeyed all this way across the centuries, across the oceans, across the mountains, across the prairies, because we are made of sugar candy!"

Nor will we journey into space, and make the solar system our own, by being made of sugar candy.

The United Kingdom is a truly great nation, a nation whose people and culture have spread across the globe, and whose language has become the world's most common second language, due in no small measure to the support of Royal Society for its nation's explorers over the centuries. As we consider the migration of human beings out into space, first to the moon and Mars and then eventually beyond, I think it is interesting to look back, and to consider the migration of the human species and its languages and cultures to all of the continents of this planet. Our forebears have left us a history filled with lessons for the future.

Some of these lessons are in evidence in my own land. America's origins do not begin on a specific date, nor do they involve any one particular group of people. Many of us in America are the descendants of pioneers from Spain, Portugal, Holland, Scotland, England, Ireland, France, Germany, Italy, and many other countries, who emigrated over many generations and settled in what became the United States, in search of new riches, new freedoms, and new beginnings. The several peoples of the British Isles were not even the first of these many groups, but they were in the end the boldest and most persistent. And so, over many generations, the primary language of the United States came to be English and our dominant cultural traditions are derived from Great Britain. Thus, while we Americans are quite a mixed bag, in many respects we are your cultural, political, and quite often genetic descendents. One of my own great-grandfathers emigrated from Scotland, another was Irish, a great-grandmother was a Hobbs, and my surname indicates the presence of a Welshman somewhere on the family tree! So my hope is that the English language will not only remain in common usage around the world, but will spread throughout the solar system over the course of the next century, as modern-day explorers like NASA astronauts Piers Sellers, Nick Patrick and others carry their British heritage with them into space. That is truly a lasting legacy for a great people.

Now, I am not a historian, but I am mindful of the lessons of history and how we can apply them to the challenges that NASA faces today in space exploration and scientific discovery. The Royal Society was one of the primary benefactors to many great maritime explorers of the 17th and 18th centuries. Today, in many respects, NASA is carrying on the same tradition of combining exploration and scientific discovery that the Royal Society initiated centuries earlier. Indeed, NASA is so beholden to the Royal Society and its traditions that two space shuttles, *Discovery* and *Endeavour*, were named in honor of sailing ships used by Captain James Cook, one of Britain's, and history's, greatest explorers. And when astronauts Dave Scott and Jim Irwin voyaged to the mountains of the Moon on the Apollo 15 mission, their command ship was also named *Endeavour*.

So in drafting my speech for today, I thought it might be insightful to consider the connection between certain lessons from Captain Cook's initial South Pacific voyage on His Majesty's Bark *Endeavour*, to the work NASA is carrying out today in exploring the planets, moons, asteroids and comets of the Solar System.

Cook's first expedition to the South Pacific in 1768 was funded jointly by the Royal Society and the British Admiralty. The primary purpose of the voyage was to obtain astronomical observations of the transit of the planet Venus, as seen from Earth, across the disk of the Sun on Saturday, June 3, 1769. The secondary intent of the voyage was to search the South Pacific for signs of a southern continent, *Terra Australis*, which had been conjectured to exist by members of the Society. He was only thirty-nine at the time and, from my present vantage point, clearly far too young to be entrusted with such major responsibilities. What in heaven's name were his superiors thinking? But I digress.

If I were speaking to the Royal *Astronomical* Society, everyone present would understand why the Royal Society was interested in having Captain Cook and a team of scientists observe the 1769 transit of Venus, and I could save a few words. But for tonight, we should probably note that, prior to the invention of radar and, later, the capability to send spacecraft to other planets, it was extremely difficult to determine the actual size of the solar system. But, using a method first proposed by Sir Edmund Halley, himself an early and renowned member of the Royal Society, it is possible to use observations of a Venus transit to calculate the distance from the Earth to the Sun, the "astronomical unit," or A.U., and with that to determine the scale of the Solar System.

Venus transits are one of the rarest predictable celestial events, typically lasting for only a few hours at a time. Between the 12th and 39th centuries they occur in a 243-year cycle, with appearances in pairs 8.5 years apart, separated by gaps of over a century. The most recent Venus transit occurred in 2004, the next one will be in 2012, and after that we will need to wait until 2117 for another. I observed the 2004 event personally, and it may not be too much to hope for that I will see the 2012 transit, but I expect I shall be missing the one after that.

The practical difficulties of making such observations were substantial in the 18th century. It is necessary to measure, quite accurately, the entry and exit times at which Venus crosses the limb of the sun, as seen from widely separated points on Earth. So, to begin, it was necessary to meet the fundamental challenge of merely traveling to various distant points on the globe, including the South Seas. This was an enormously difficult prospect in its day. Considered objectively, one must say that it was fully as difficult, dangerous and time consuming for Cook and *Endeavour* to reach the South Pacific as it will be for the first voyagers to reach Mars. Indeed, my personal opinion is that it was far more so, given the technology of those times. I believe that this is an important perspective for those who believe, somehow, that the exploration of space is uniquely difficult in comparison with the exploration of Earth by Europeans. And so this is the first lesson. Are we to quail before multiyear voyages to uncertain destinations, when our ancestors did not?

Among the many challenges of long sea voyages in the 18th century was, first, the basic task of determining one's location! Accurate and consistent timekeeping at widely separated points, equivalent to knowing one's longitude, was still a major challenge in 1769, and nearly impossible to do while aboard ship. Today, we take for granted GPS navigators that receive precise timing signals from satellites with atomic clocks in orbit around Earth. Back in 1769, Captain Cook did not even have the benefit of an accurate chronometer. It was not until his second voyage to the South Pacific a few years later that Cook carried with him the K1, a copy of Harrison's H4, the clock that won him the famed Longitude Prize in 1773. Indeed, modern-day navigators and timekeepers, using GPS, are forever indebted to John Harrison and his famous clocks, some of which can be seen today at the Greenwich Observatory.

Captain Cook learned the value of accurate navigation and precise timing in the late 18th century, and the ability to carry out the primary purpose of his voyage was only barely possible with the technologies available to his expedition at that time. He didn't even have a good map; indeed, his job was in part to help make them. Modern-day explorers and scientists also know the value of a good map and accurate GPS measurements. Data from NASA's LANDSAT satellites provides the backdrop for maps provided by Google Earth and others. We will need a similar navigation infrastructure on the moon for future explorers and scientists. Scheduled for launch in 2008, NASA's Lunar Reconnaissance Orbiter with its laser altimeter and other instruments will provide an accurate global map of the moon for future explorers. We're still formulating our plans for providing communication and navigation for future explorers on the moon, but I can foresee NASA collaborating with other spacefaring nations like the United Kingdom in providing such infrastructure.

Such collaborations again have a long and honorable history. In another interesting parallel to space exploration today, the effort to observe the 1769 transit of Venus was an early example of international scientific collaboration. Cook's expedition to the South Seas and his sighting of the Venus transit from Tahiti was but one of many similar efforts, with scientists and explorers from Britain, Austria, France and other countries traveling to Siberia, Norway, Madagascar and the southern tip of Africa. Catherine the Great of Russia even invited astronomers to observe the transit of Venus from her observatory in Saint Petersburg.

Similarly, and as of today, NASA has 58 on-going space and Earth science missions, and over half of these missions have some form of international participation. Two-thirds of all NASA missions currently under development incorporate international partners. And of course, NASA's premier human spaceflight program, the development of the International Space Station, is an effort involving some 15 nations.

Like the collaboration for the Venus transit, NASA's partnerships in space exploration and scientific discovery take many forms, with various levels of contribution. For example, we are contributing two payloads to India's Chandrayaan-1 mission to the moon, planned to be launched next year. For the CALIPSO mission launched earlier this year, NASA developed a LIDAR payload, the French Space Agency (CNES) integrated that payload to their satellite bus, and NASA launched it. The British National Space Center provided a high-resolution atmospheric sounding payload to the Aura Earth science mission launched two years ago. In the next decade, the European Space Agency will launch the James Webb Space Telescope aboard an Ariane V rocket.

One of the more unusual aspects of Cook's first expedition is that few members of the crew of *Endeavour* contracted scurvy, a disease now known to result from a lack of Vitamin C. By the mid-1700s, it was widely known that a poor diet caused scurvy, but what specifically caused it was not known. Captain Cook led by example, and motivated his sailors into eating Vitamin C-rich, but not very tasty, sauerkraut by being the first to eat it during his meals.

While today's space station crew members don't get scurvy, they face other medical issues. For example, muscle and bone density loss due to a lack of tension on the human body in zero-G is well known. While there is a significant degree of variability between station crew members in the amount of bone loss, the average density lost in the spine and hip areas is about 1 percent per month. This rate of bone loss for astronauts is 10 times worse than for those who suffer from osteoporosis here on Earth. Thus, like sailors of the 18^{th} century, our astronauts on the space station or in future missions to Mars face significant medical hazards, in the form of bone fractures and kidney stones that could jeopardize their health and their mission. The equivalent of sauerkraut for modern-day astronauts is the unpleasant but necessary nutrition and exercise regimen to create muscle tension and mitigate bone loss. But these are stopgaps, incomplete and unsatisfactory at best. Whatever therapy is finally developed to control bone loss in astronauts will have application to sufferers of osteoporosis everywhere. Astronauts already have conducted clinical trials for new osteoporosis drugs onboard the space station. We have much to learn, and in learning we will create knowledge that can help people everywhere.

For exploration beyond low Earth orbit, radiation is another hazard to be dealt with. (At this point, I will again quote Churchill, who famously said that the grammatical prohibition against ending a sentence with a preposition is "an inconvenience up with which I shall not put.") The Earth's atmosphere and especially its magnetic field shields us from nearly all of the effects of solar flares and galactic cosmic radiation, even to the extent of providing substantial protection for low-orbiting astronauts. Despite this shielding effect, periodic and highly intense solar storms wreak havoc with power grids on Earth and satellites in high orbit. On several occasions, space station astronauts have hunkered down in heavily shielded areas of the station when solar flares or coronal mass ejections were predicted to be heading toward Earth. And as we venture farther away from Earth, the need to protect them from this energetic particle radiation becomes more critical. For example, back in August 1972, between the Apollo 16 and 17 missions, a powerful solar flare occurred that would have seriously endangered our astronauts if they had been en route to the moon or on the lunar surface at that time. An even larger sequence of solar events occurred in the fall of 2003. We must provide our astronauts with both warning systems and effective safeguards.

Looking through the eyes of multiple spacecraft over the past five decades, we have seen that in truth the planets of the solar system are embedded in the heliosphere, the exotic outer atmosphere of the sun, emanating from and shaped by its intense magnetic field. This heliosphere is analogous, in many ways, to the winds and currents of the Pacific Ocean that propelled Captain Cook's *Endeavour*, but which also endangered the vessel and crew during periodic storms. Thus, we must build our space ships in ways that shield the astronauts and instruments inside, and we must provide timely warnings and predictions of "solar storms" just as we do now with weather forecasts here on Earth. Space weather monitoring and forecasts need to be extended beyond low Earth orbit to cislunar space and, eventually beyond, when we begin missions to Mars. This effort to safeguard planet Earth and our astronauts from solar storms must be an international endeavor, just like information from an international network of weather satellites and forecast centers today is shared around the world. We will benefit all mankind in the process by planning our heliophysics missions together. Earlier this month, NASA launched the STEREO mission, consisting of two satellites intended to provide 3-D images of the effects of coronal mass ejections and other solar activity on Earth's magnetosphere. The STEREO mission had several international partners, and will provide warnings that are useful around the world, but NASA cannot "go it alone." We must work together.

Scientific discoveries are sometimes elusive, but we must persevere. As things turned out, despite the best efforts of Captain Cook and his men and the other international collaborators in measuring the Venus transit, the separate measurements taken by the various scientific expeditions onboard the *Endeavour*, at Point Venus in Tahiti, and other places around the globe varied greatly, and were, inevitably, inconclusive. It turned out to be very difficult to determine the precise limb crossing times for Venus against the solar background. A now-notorious observational surprise, the so-called "black drop effect," smears the image of Venus precisely as it becomes tangential to the solar limb. In the end, none of the observations of the 1769 transit, whether from Cook's team or others, were very good. The astronomical unit would not be accurately determined until the 1880s, when American astronomer Simon Newcomb published a value of 149.6 million km, using data from the four prior Venus transits.

Thus, we must recognize that while the mysteries of the universe may not elude Stephen Hawking, these mysteries do frustrate the rest of us who are mere mortals. We must be resolute in our convictions, and despite setbacks, we must recognize that progress through human exploration and scientific discovery is a goal worthy of the costs and risks of the enterprise. Again to echo Churchill, we are not made of sugar candy.

But the disappointment encountered by Cook's expedition yields another lesson for space mission planners today. Cook's voyage was not judged, nor intended to be judged, solely on its ability to obtain accurate measurements of the transit of Venus. Indeed, Cook is today remembered above all else for his discovery, the first by European voyagers, of the previously unknown continent of Australia. Who today would label Cook's first South Pacific voyage a failure because the measurements of the Venus transit were inconclusive? We must remember this and similar experiences when our future space missions encounter difficulties. And we must plan them so that they are not hostage to a single piece of good fortune as a measure of their overall success.

There is yet another lesson to be gained by looking back across the centuries at the voyages of *Endeavour*. Although Captain Cook no doubt considered his vessel to be the apotheosis of the shipbuilding arts as they were then known, we can see in retrospect that the *Endeavour* occupies but one point along a curve of ever increasing maritime capability, beginning for Europeans with the Viking longships and culminating in today's supertankers. We must realize that there will be a similar performance curve for space systems, and that we have not as yet advanced very far along it. We are at the dawn of the space age; metaphorically, we are sending out longships. We have a long, long way to go to get to supertankers. We must constantly question our assumptions as to how we build and operate our spacecraft and launch vehicles, because we have a lot yet left to learn. Each generation of ships must improve upon the last.

For example, the space shuttle system, including the orbiter, solid rockets and external tank, requires almost 2 million labor-hours to prepare for launch. We have analyzed the processing labor required for other launch vehicles, both foreign and domestic, manned and unmanned. Using these other launch vehicle systems operating costs and labor-hours as a guide, I believe that NASA's next generation crew launch vehicle, the Ares I, should require an order of magnitude fewer labor hours to process than the space shuttle. The savings in launch vehicle operating costs can then be applied to future systems and bolder missions. With the retirement of the space shuttle in 2010, and development beginning for NASA's new *Orion* Crew Exploration Vehicle and Ares I Crew Launch Vehicle, we are beginning to lay the keel for the next generation of space ships. Now is the time to question our operating assumptions and technical dogmas.

Reflecting upon his journeys, Captain Cook once said, “I had ambition not only to go farther than any man had ever been before, but as far as it was possible for a man to go.” While some people might ridicule such bold ambitions, I think that it reflects the determination innate in all of us to push the limits of our technological capabilities and human faculties. However, I will express a certain lament to those sympathetic and like-minded members of the Royal Society who are concerned, with me, that our broader society today often seems to suffer from a lack of imagination in grasping the importance of the challenge before us.

One of the minor misfortunes of modern life in our major cities is that our night-time lighting has drowned out our view of the rich constellation of stars and planets in the night sky, and we find other idle pursuits, such as television, to occupy our time. Thus, we today do not look up nearly as often to marvel at the beauty and mystery of the night sky as did our ancestors, who imagined the stars to represent constellations of mythological beasts and legends, while the planets represented gods. I am happy that we have progressed beyond this. To me the view of Hadley Rille from a camera mounted on the Apollo lunar rover is more exciting than imagining the moon to be the huntress Diana. But, there is no question that we modern folk are less concerned with the heavens than were our ancestors.

But if we do the right things, maybe we can alter this perspective. The British Royal Astronomical Society recently released a report advocating the expansion of British involvement in human space exploration. I hope that report receives sober consideration in the policy circles of the United Kingdom, and I hope that I can count on you to be among the international partners who, with the United States, work to develop the first permanent lunar outpost in the next decade. And last month I made the decision, the culmination of 18 months of work by NASA engineers and scientists, that we could effectively and safely conduct a space shuttle servicing mission to the Hubble Space Telescope to extend the life and capabilities of this great observatory. I have been struck by the tremendously positive response this decision has received, by the way that people from all over the world have been awed and inspired by Hubble pictures revealing a few of the secrets of our universe. Hubble provides glimpses into the universe that are far, far beyond the scale of the astronomical unit, the objective for Cook’s first voyage to the South Pacific.

The view of our vast universe provided by Hubble uplifts us; it gives us a measure of hope. It was the same when the first man flew in space, and when the first man set foot upon the moon. We see a little of it each time a space shuttle crew returns from yet another mission in the sequence necessary to assemble the International Space Station, quite possibly the greatest construction project in the history of mankind. We will see it again, at its peak, when the first astronaut places her boot on the surface of Mars. The human species was not crafted solely for safe places and prosaic times. We are, each of us, descended from people who left their homeland in search of what lay beyond. Today, what lies beyond is space. And so, quoting Professor Hawking: "To confine our attention to terrestrial matters would be to limit the human spirit."

I believe with all my heart that, with the exploration of space, we are embarked upon the boldest human adventure yet conceived. We are limited only by our imagination, ambition, ingenuity, persistence and leadership. But, "We have not journeyed all this way across the centuries, across the oceans, across the mountains, across the prairies, because we are made of sugar candy!"

Thank you.