JULY/AUGUST 2006

# SPACES THE MAGAZINE OF THE AMERICAN

### THE MAGAZINE OF THE AMERICAN ASTRONAUTICAL SOCIETY ISSUE 4 VOLUME 45

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JULY/AUGUST 2006 ISSUE 4 – VOLUME 45

### THE MAGAZINE OF THE AMERICAN ASTRONAUTICAL SOCIETY

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Thirty years ago, the Viking program sent two Orbiters and two Landers on a multi-year mission to Mars. Following up on previous flybys and orbiters, the Viking mission deployed more than four dozen scientific instruments, revolutionized our understanding of Mars, and provided stunning new pictures of the Red Planet. by Joel S. Levine

### The Golden Age of Mars Exploration

With the landing of Viking, Mars moved from an object of our imagination to a destination of exploration and discovery. Since then, our understanding of Mars has progressed immensely and our understanding of life on Earth has radically changed. As a consequence, our expectations for life on Mars has waned and waxed, to the point where the quest for evidence for life on Mars is now an exciting and legitimate scientific endeavour. by Michael Meyer

### **A Different Vision for Space Exploration**

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On 14 January 2004, President George W. Bush outlined a new focus for NASA that has come to be called the "Vision for Space Exploration," which emphasizes the development of new human spaceflight systems capable of carrying crews beyond low-Earth orbit out to the Moon, Mars, and beyond. A year and a half later, is it time to ask whether this human-focused approach to space science and exploration is the best way to allocate our limited resources? by Donald A. Beattie

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# Common Data, Different Conclusions

write this message as Space Shuttle Discovery has just returned safely to Earth from a spectacular flight. Mission STS -121 delivered over 28,000 pounds of experiments, equipment and supplies and ESA astronaut Thomas Reiter to the International Space Station. It repaired the mobile transporter to enable resumption of Station assembly. And in doing so it covered 5.3 million miles in 202 orbits over 13 days. It was breathtakingly successful, and paved the way for the 18 Shuttle flights needed to complete ISS, and hopefully a Hubble repair mission, before Atlantis, Endeavour, and Discovery are retired in 2010. President Bush noted that "America's space program is a source of great national pride, and this mission has been another



important accomplishment in advancing space science, human space flight and space exploration."

STS -121 received meticulous technical, management and media attention because of continuing challenges in eliminating external tank insulation debris, the cause of vehicle damage that led to the Columbia tragedy. Technical and management debates were reported often, and in some detail. At times there was the inference that decisions made in the presence of differing conclusions were a sign of schedule pressure, or of closed minds, or of overbearing management. Always a possibility, these and other impediments to making good decisions must constantly be guarded against. We should never loose sight of the fact, though, that differing conclusions are the engine that powers the pursuit of truth, as they did here. Shuttle Program Manager Wayne Hale observed, "The fact that people look at common data and sometimes reach different conclusions is not a bad thing. It keeps us sharp and keeps us smart." And sharp and smart is what we must certainly be in pursuing the exploration and development of space.

Our heartiest congratulations to the entire Space Shuttle team and to the ISS team around the world, and to astronauts Steve Lindsey, Mark Kelly, Michael Fossum, Piers Sellers, Lisa Nowak, Stephanie Wilson and Thomas Reiter. We look forward to the flight of Atlantis and all the remaining Shuttle missions.

Mark Craig mark.k.craig@saic.com

### **ON THE COVER**

**FRONT:** Astronaut Piers J. Sellers, STS-121 mission specialist, participates in the mission's third and final extravehicular activity to demonstrate orbiter heat shield repair techniques. (Source: NASA)

**BACK:** Launched on July 12, 2006, Bigelow Aerospace's Genesis 1 is the first inflatable space habitat prototype designed, built, and launched by a private company. (Source: Bigelow Aerospace)

### **Attention AAS Fellows!**

Special lapel pins for AAS Fellows were recently mailed out. If you are an elected AAS Fellow and did not receive a pin, please notify the AAS Business Office at aas@astronautical.org.

# Thirty Years After: The Science of the Viking Program and the Discovery of a "New Mars"

Thirty years ago, the Viking program sent two Orbiters and two Landers on a multi-year mission to Mars. Following up on previous flybys and orbiters, the Viking mission deployed more than four dozen scientific instruments, revolutionized our understanding of Mars, and provided stunning new pictures of the Red Planet. by Joel S. Levine

On 19 June 1976, the Viking 1 Orbiter achieved orbital insertion around Mars. The next day, the Viking 1 Lander soft-landed on the surface in an area known as Chryse Planitia, becoming the first human-made object to land on Mars. Less than two months later, on 7 August, the Viking 2 Orbiter achieved Mars orbital insertion, while the Viking 3 Lander touched down on Utopia Planitia on 3 September. By then, four Viking Mars spacecraft—two in orbit and two on the surface – were simultaneously collecting new and previously unobtainable data and transmitting it back to Earth.

The first U.S. missions to Mars were all flybys. Mariner 4 (which passed within 9,850 kilometers of Mars during its closest encounter on 14 July 1965), Mariner 6 (31 July 31), and Mariner 7 (5 August 1969) all showed Mars to be a seemingly desolate, inhospitable world like our own Moon. The thinking about Mars changed with Mariner 9, the first Mars orbiter, which achieved Mars orbital insertion on 13 November 1971. Mariner 9 showed that Mars was an intriguing object with very diverse and puzzling geological features, including very large impact craters (Argyre), the largest canyon (Valles Marineris), and the largest volcano (Olympus Mons) in the Solar System.

The Viking Project was a truly "one NASA" project, with NASA's Langley Research Center responsible for the development and management of the entire Viking Mission. The Jet Propulsion Laboratory (JPL) was responsible for the orbiters, the tracking and data acquisition, and mission control. The Lewis Research Center (later renamed the Glenn Research Center), was responsible for the launch vehicle. The Kennedy Space Center was responsible for the launch. The Martin Marietta Aerospace Corporation, now Lockheed-Martin Corporation, built the landers and also had the responsibility for its integration with the JPL-provided orbiter. Other NASA centers, including the NASA Ames Research Center, the Goddard Space Flight Center and the Johnson Space Flight Center, provided scientific and engineering support to the Viking Project.

### Viking Science Package Overview

The two Viking Orbiters and Landers carried a very impressive array



A color image of Valles Marineris, the great canyon of Mars; north toward top. The scene shows the entire canyon system, over 3,000 km long and averaging 8 km deept. This image is a composite of Viking medium-resolution images in black and white and low-resolution images in color. Layers of material in the eastern canyons might consist of carbonates deposited in ancient lakes. Huge ancient river channels began from Valles Marineris and from adjacent canyons and ran north. Many of the channels flowed north into Chryse Basin, which contains the site of the Viking 1 Lander and the future site of the Mars Pathfinder Lander. (Source: Jet Propulsion Laboratory)

of scientific instrumentation. The instrument package on the Orbiters included two vidicon cameras for imagery from orbit, an infrared spectrometer for Mars Atmospheric Water Detection (MAWD), and an Infrared Radiometer for Thermal Mapping (IRTM). During their descent to the Martian surface, the Landers took measurements of the ionosphere and the composition, structure, and dynamics of the Martian atmosphere during entry. The Landers carried the most comprehensive set of scientific instruments ever deployed to another planetary body, including visual-light cameras, meteorological and atmospheric instruments, seismometers, magnets, and, most notably, a set of three different biology experiments. In addition, the radio and radar systems on the orbiters and landers provided measurements of atmospheric parameters, celestial mechanics and a test of general relativity.

### **Orbiter Science**

The Viking Orbiters obtained 52,000 images of the Martian surface from orbit, with larger format and a spatial resolution of about 100-150 meters, about a factor of 10 increase compared to the Mariner 9 cameras. The scientific objectives of the orbiter imaging systems included characterization of potential landing sites in sufficient detail to support future missions; studying the topographic, photometric, and colorimetric characteristics of the surface; and investigating in greater detail the various interesting geologic features (volcanoes, impact craters, canyons, channels, faults, polar cap formations, etc.) discovered by Mariner 9.

An example of Viking 1 imagery can be seen on page 4. The first is a composite image of Valles Marineris, the great canyon of Mars, with north towards the top, made up of a number of mediumresolution black and white and low-resolution color photos. The scene shows the entire canyon system, over 3,000 km long and averaging 8 km deep, extending from Noctis Labyrinthus in the west to the chaotic terrain to the east. Scientists still



This mosaic of Mars is a compilation of images captured by the Viking Orbiter 1. The center of the scene shows the entire Valles Marineris canyon system, over 3,000 km long and up to 8 kilometers deep, extending from Noctis Labyrinthus, the arcuate system of graben to the west, to the chaotic terrain to the east. (Source: Jet Propulsion Laboratory)

don't fully understand how this monumental structure was formed, but many now think that liquid water may have played a major role in the process. The connected chasma or valleys of Valles Marineris may have formed from a combination of erosional collapse and structural activity. Layers of material in the eastern canyons might consist of carbonates deposited in ancient lakes. Huge ancient river channels began from Valles Marineris and from adjacent canyons appear to run north. Many of the channels flowed north into Chryse Basin, which contains the site of the Viking 1 Lander and, nearly two decades later, the future site of the Mars Pathfinder Lander Sojourner. Olympus Mons is nearly the size of the state of Montana, covering an area roughly 600 kilometers in size, with a summit caldera that rises 24 kilometers above the surrounding plains.

Other instruments on board the orbiters helped characterize the planetwide atmospheric and surface properties of this fascinating body. MAWD found that water in the atmosphere is highly variable, changing with local time, elevation, latitude and season. In other words, Mars, like Earth, has active weather and variable climates. Atmospheric water vapor was found to vary from 0 parts per million (ppm) in the winter hemisphere to 85 ppm near the polar region of the summer hemisphere. The atmosphere above the north polar cap in midsummer was found to be saturated, providing strong evidence that the permanent ice cap is composed of water. The water vapor in the atmosphere is concentrated near the surface and moves from one hemisphere to the other during the changing seasons.

Meanwhile, IRTM mapped the temperature and thermal inertia of the surface. The question of the composition



This picture of Mars was taken July 21 – the day following Viking I's successful landing on the planet. The local time on Mars is approximately noon. (Source: Jet Propulsion Laboratory)

of the Martian polar caps was partially settled by Mariner 7 measurements. The southern winter pole cap was found to be at a temperature consistent with frozen CO2. A similar result was found for the northern winter cap from Mariner 9 measurements. The composition of the permanent or residual polar caps was a subject of debate prior to Viking. Viking measured the temperature of the permanent (residual) polar cap at 200 - 215K, indicating that the permanent cap is composed of water ice, a result consistent with the MAWD measurements. The amount of water deposited at the poles was found to be many orders greater than in the atmosphere.

### **Entry Science**

During entry, the Viking Landers obtained the first in situ measurements of the pressure, temperature and composition of the atmosphere of Mars. These results provided unexpected evidence of the history and ultimate fate of Mars' early atmosphere, and clues as to whether Mars might have ever supported an environment hospitable to life.

The mass spectrometers aboard the two Viking Landers measured the chemical and isotopic composition of the Martian atmospheric as they decelerated from over 10,000 kilometers per hour toward a soft landing. Along with mass spectrometers deployed on the surface, the Viking Landers found isotopes of carbon ( $^{12}$ C and  $^{13}$ C) and oxygen ( $^{16}$ O and  $^{18}$ O) in carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO) and oxygen (O<sub>2</sub>), and nitrogen ( $^{14}$ N and  $^{15}$ N), other isotopes of argon ( $^{36}$ Ar and  $^{39}$ Ar), neon, krypton, and xenon ( $^{129}$ Xe).

The isotopic abundance of carbon and oxygen in the atmosphere of Mars was found to be similar to that in the Earth's atmosphere. A surprising result was the discovery that <sup>15</sup>N is enriched with respect to <sup>14</sup>N by a small factor. The measured enrichment of <sup>15</sup>N may be attributed to the selective escape of <sup>14</sup>N from an atmosphere initially rich in  $N_2$ . The measured ratio of <sup>15</sup>N to <sup>14</sup>N suggests that Mars had a significantly denser atmosphere in its past. The denser atmosphere is also consistent with the Viking Orbiter images suggestive of flowing water on Mars. (The current atmosphere pressure on Mars of about 8 millibars cannot support the presence of liquid water on the surface of Mars. For comparison, the surface atmospheric pressure on Earth is 1013 millibars.)

However, the mass spectrometers on the Landers did not find any evidence of organics on the Martian surface. This was considered a very surprising null measurement, since organics are regularly and continuously supplied to a planetary surface by meteorite impact, and had a significant impact on the interpretation of the Mars biology experiments, as we will see below.

### Lander Images

The Landers took about 4,500 images from the surface Mars. The surface and sky were found to have an orange to brownish color. The color of the sky was due to large amounts of wind-blown surfaced dust in the atmosphere. The rocks on the surface were found to be basaltic igneous, or volcanic in origin.

Above is the first color picture from the surface of Mars, taken 21 July 21, the day after Viking I's successful landing on the planet. The local time on Mars is approximately noon. The view is southeast from the Viking. Orange-red surface materials cover most of the surface, apparently forming a thin veneer over darker bedrock exposed in patches, as in the lower right. The reddish surface materials may be limonite (hydrated ferric oxide, or rust). Such weathering products form on Earth in the presence of water and an oxidizing atmosphere, another piece of tantalizing evidence about the early environment on Mars. The sky has a reddish cast, probably due to scattering and reflection from reddish sediment suspended in the lower atmosphere. The scene was scanned three times by the spacecraft's camera number 2, through a different color filter each time.

On page 8 is Viking 2's first picture on the surface of Mars, taken within minutes after the spacecraft touched down on 3 September 1976. The scene reveals a wide variety of rocks littering a surface of fine-grained deposit. Boulders in the 10 to 20 centimeter size range, with some holes and other features apparently having been carved by wind action. Many of the pebbles have tabular or platy shapes, suggesting that they may be derived from layered strata, though whether they were deposited by wind or perhaps liquid water is unknown. The fluted boulder just above the Lander's footpad displays a dust-covered or scraped surface, suggesting it was overturned or altered by the foot at touchdown.

### Meteorology

The Lander meteorology instruments found that the surface atmospheric pressure varies seasonally by about 30% due to the condensation of carbon dioxide at the polar caps. The first weather report from the surface of another planet was given by Seymour Hess, Head of the Viking Meteorology Team:

> Light winds from the East in the late afternoon, changing to light winds from the southeast after midnight. Maximum winds were 15 miles per hour. Temperatures ranged from minus 122 degrees Fahrenheit just after dawn to minus 22 degrees Fahrenheit... Pressure steady at 7.70 millibars.

### **Biology Experiments**

While the Viking missions were responsible for bringing more and more different types of instruments to Mars than ever before, it was the Martian biology experiments that were the focus of most of the scientific and popular interest in the mission. The Viking Landers contained three different biology experiments to search for the presence of life on Mars; the Pyrolytic Release Experiment (The Carbon Assimilation Experiment), the Labeled Release Experiment and the Gas Exchange Experiment. In an attempt to minimize any ambiguities in the results, these experiments would test the Martian soil for a number of different possible biological markers. Nevertheless, even the best instruments that could be flown at the time could, in the end, not yield a definitive statement as to be entirely consistent, though not dependent on, a possible biological interpretation.

Finally, the Gas Exchange Instrument periodically sampled the headspace gases above a Martian surface sample incubating under dry, humid, or wet conditions and analyzed the gases with a gas chromatograph. The instrument was designed to distinguish between gas changes arising from microbial metabolism and those arising from purely chemical reactions or physical phenomena, such as sorption and desorption, by recycling the soil

"The surface of Mars is obviously highly reactive and contains at least one and probably several highly oxidizing substances. While inorganic chemical reactions may be sufficient to explain the data seen, biological processes cannot be ruled out at this time."

whether Mars has, or has ever had, an active biosphere.

The Carbon Assimilation Experiment was designed to detect the synthesis of organic matter in Martian surface material from atmosphere CO or  $CO_2$  or both. The experiment assumes that Martian life would be based on carbon and that this carbon would necessarily cycle through the atmosphere. In two papers, the Carbon Assimilation Experiment Science Team summarized all of the experimental data, including the results of the two experiments on Mars and concluded "that they are unlikely to have a biological explanation."

Meanwhile, the Labeled Release Experiment sought to detect heterotrophic metabolism by monitoring radioactive gas evolution. A small amount of mildly radioactive "nutrient" containing seven <sup>14</sup>C-labelled organic substrates was added to a sample of surface material. Unlike the Carbon Assimilation Experiment results, those from the Labeled Release Experiment were determined to

sample. A chemical or aqueous physical reaction would be reduced or eliminated in subsequent cycles, whereas a biological system would perpetuate itself. The gas changes from the former would be reduced or disappear; from the latter they would continue or increase. The Gas Exchange Instrument science team concluded that the measured response of the Martian surface samples to water vapor resulting in  $O_2$  output was ascribed to the presence of superoxides in the Martian surface material and that all the gas changes observed in the experiment could most easily be explained or demonstrated by plausible chemical reactions that required no biological processes. Again, though, the team could not rule out any biological activity based solely on the results from the Gas Exchange Instrument.

Viking Project Scientist Gerald A. Soffen summarized the results of the Viking Biology Experiments in the following statement:



Viking 2s first picture on the surface of Mars was taken within minutes after the spacecraft touched down on September 3. (Source: Jet Propulsion Laboratory)

The biological results were by far the most complex of all investigations. There was no unambiguous discovery of life by the Viking Landers, and three of the results appear to indicate the absence of biology in the samples tested. Nevertheless, the experiments gave significant results revealing the chemical nature of the Martian surface and at least one result that could still be consistent with a biological interpretation. One experiment indicates that the Martian soil has an agent capable of rapidly decomposing organic chemicals used in the medium or that life is present...In another experiment the addition of water vapor to the Martian sample caused a vigorous release of oxygen for a few hours. This oxygen release is heat stable. Heating the dry sample generates large amounts of CO and CO<sub>2</sub>. In one experiment a small amount of carbon dioxide (or carbon monoxide) was incorporated into the organic fraction (or made organic de novo). This process does not appear to be stimulated by light or the addition of water vapor. The surface of Mars is obviously highly reactive and contains at least one and probably several highly oxidizing substances.

While inorganic chemical reactions may be sufficient to explain the data seen, biological processes cannot be ruled out at this time.

### Conclusions

Viking discovered a Mars that was very different from the Mars found by

surface of Mars. But Viking did discover a surface unlike any other on the Solar System—a surface exhibiting very high chemical reactivity, most probably formed by the deposition of chemically active atmospheric gases, like hydrogen peroxide  $(H_2O_2)$  and ozone  $(O_3)$ , onto the surface of Mars.

Viking Project Scientist, Gerald A. Soffen, believed that the Viking explora-

# "Comparative planetology was conceived with Mariner and born with Viking."

Mariner 4, 6 and 7. The new, exciting, more Earth-like Mars was hinted at by the Mariner 9 orbiter and confirmed by Viking. Viking discovered some very fundamental things about Mars. Viking discovered the presence of nitrogen in the atmosphere, a key ingredient needed for life. Viking made the first measurements of the isotopic composition of carbon, oxygen, nitrogen and the noble gases in the atmosphere of Mars. The ratio of <sup>15</sup>N to <sup>14</sup>N suggested that Mars may have lost more than 99% of the total mass of its atmosphere. The denser atmosphere in the past may explain the presence of flowing water earlier in the history of Mars first discovered by Mariner 9 with additional and higher spatial resolution examples provided by the Viking orbiters. Viking did not measure organics or life at the

tion of Mars came at an important time in history when humankind was just becoming aware of the Earth as a planet. Soffen added: "Comparative planetology was conceived with Mariner and born with Viking." After Viking, our picture of Mars would never be the same!

Dr. Joel S. Levine is a Senior Research Scientist in the Science Directorate, NASA Langley Research Center, Hampton, VA. Dr. Levine is Principal Investigator of the Aerial Regional-scale Environmental Surveyor (ARES) of Mars, a robotic, controlled, rocket-powered airplane. In 2002, ARES was one of the four finalists in the first NASA Mars Scout Mission competition. ARES was re-submitted in August 2006, for the second Mars Scout Mission competition.

# The Golden Age of Mars Exploration

With the landing of Viking, Mars moved from an object of our imagination to a destination of exploration and discovery. Since then, our understanding of Mars has progressed immensely and our understanding of life on Earth has radically changed. As a consequence, our expectations for life on Mars has waned and waxed, to the point where the quest for evidence for life on Mars is now an exciting and legitimate scientific endeavor. by Michael Meyer

In 1872, the HMS *Challenger* set sail from Plymouth, England, in part to resolve a debate within the Royal Society as to whether there is life in the ocean's dark depths, otherwise known as the azoic zone. Over the next three years, Challenger found amazing biological diversity throughout the ocean and collected enough data and samples to fill fifty volumes of material. The sheer volume of information generated by the Challenger mission helped establish the scientific discipline of oceanography. Since then, oceanography has progressed from a science devoted to cataloguing novel phenomena to one devoted to an understanding of processes and testing of hypotheses.

Interestingly enough, it was during the exploration of the Galapagos Rift in 1977, just after Viking landed on Mars, that bizarre life forms were found at hydrothermal vents on the sea floor. Finding life at above surface-boiling temperatures suddenly expanded our view of the extreme capabilities of life on Earth and opened the landscape to where life might be possible elsewhere.

Since then, life has been found in hot springs, in permafrost, in acid pools, in ancient salt deposits, and in all but the most extreme deserts. Life on Earth, it seems, can hang on in the most inhospitable of environments so long as it has access to liquid water. The results begged an obvious question: if there is liquid water on other planetary bodies, which seems to be one of the few absolute necessities for life here on Earth, can there be life on these bodies as well?

With this insight, NASA's Mars Exploration Program has pursued a "follow the water" theme. Water is as a key to finding where life may exist, or existed; it is central to tracking climate, past and present; a key to understanding geological processes over time; and as a resource for future human exploration. The Mars Global Surveyor, Mars Odyssey, the Mars Exploration Rovers, and Mars Express have all found evidence that liquid water once existed on the Martian surface. The focus of the Program is now turning to questions of when water may have existed on Mars, and for how long. As we come to understand the answers to these questions, we come closer to determining if Mars has ever supported life and, if so, where evidence of that life might be preserved.

But looking for life is a challenge, intellectually and operationally. If Martians were like scientists on Earth and left their pens lying around like in the picture below, they'd be pretty easy to find! However, even if Martians were to resemble terrestrial organisms like crustose lichen, finding and recognizing such subtle signs of life would be a huge challenge. If Martian life is somehow markedly different from what we are familiar with here on Earth, then the job becomes much more difficult. Since without knowing exactly what we are looking for, we need to rely upon a well-reasoned approach on how to go about looking for life, extremely capable instruments to tease out the signs of life from a huge amount of background noise, and, of course, missions to get those instruments to Mars.

For several years, the Mars Exploration Program has been successful in



Crustose lichen and a geologist's pen on a rock formation reminiscent of Mars. The term "crustose" applies to the appearance of this life form, which can often look very similar to an abiotic mineral deposition. If the only life forms Mars ever supported were similar to these lichens, finding evidence of their existence would be a significant scientific challenge. (Source: Michael Meyer)

launching a spacecraft at every twentysix month opportunity. This has enabled a synergistic fleet of spacecraft, each with distinct capabilities, able to provide the different perspectives needed to discover where water may have existed on Mars, when, and for how long. As in oceanography in the last century, our progress in understanding Mars is growing from "what's there?" to an understanding of global processes through time and a growing ability to build and test different hypotheses. A short review of the currently operating and developing Mars missions The Mars Odyssey was launched April 2001, and its prime-mapping mission began in March 2002. Its suite of gamma-ray spectrometer instruments has provided strong evidence for large quantities of water-ice mixed into the top layer of soil poleward of 60 degrees both north and south. Odyssey's Thermal Emission Imaging System (THEMIS), a mid-infrared camera, has also provided information on the detailed distributions of different minerals throughout the Martian landscape. A layer of olivine-rich rock in one canyon near Mars' equator

"Life on Earth, it seems, can hang on in the most inhospitable of environments so long as it has access to liquid water. The results begged an obvious question: if there is liquid water on other planetary bodies, which seems to be one of the few absolute necessities for life here on Earth, can there be life on these bodies as well?"

shows how our scientific quest has progressed and portends exciting discoveries in the near future.

Mars Global Survey (MGS) was launched in 1996 and has exceeded, in spectacular fashion, its primary mapping mission. It has collected more data than any other previous Mars mission. Some of the mission's most significant findings include: gullies which suggest recent liquid water at the Martian surface; evidence for extensive layering of rocks possibly from lakes in the planet's early history; topographic confirmation that the southern hemisphere is higher in elevation than the northern hemisphere; identification of gray hematite, a mineral that forms in aqueous environments; and extensive evidence for the role of dust in reshaping the recent Martian environment. MGS provided valuable details for evaluating the risks and attractions of landing sites for the Mars Exploration Rover missions and will continue to do so for the coming lander missions of Phoenix and Mars Science Laboratory.

suggests that the site has been dry for a long time, since olivine is easily weathered by liquid water. However, other minerals such as hematite have suggested a water-borne period. THEMIS observations have helped us understand the thermophysical properties of the Martian surface, such as the extent of rocky or dusty areas in different locations. In addition to its primary science mission, Odyssey has served as a node on the interplanetary Internet, relaying over 90 percent of the data beamed from the surface by the Mars Exploration Rovers to eager to scientists back on Earth during its twice-daily pass over each rover.

The Mars Exploration Rovers, Spirit and Opportunity, are mobile robotic field geologists sent to examine clues about the environmental history, particularly the history of water, at their two unique sites. Spirit is exploring inside Gusev Crater, a bowl 150 kilometers in diameter. Orbital images suggest Gusev may have once held a lake fed by inflow from a large valley network feeding in from highlands to the south. Spirit landed in January 2003 on a plain strewn with loose rocks. The rover found that the rocks are volcanic with slight alterations. By June, Spirit had driven to Columbia Hills about 2.6 kilometers from the landing site in a quest to find exposed bedrock. Exploring in the hills since then, Spirit has found an assortment of rocks and soils bearing evidence of extensive exposure to water, including the iron-hydrogen-oxide mineral goethite and sulfate salts. Spirit is now "wintering over" near a feature dubbed Home Plate in the Columbia Hills and conducting intensive measurements of the local area.

In an example one the results from an earlier mission supporting the planning for a later one, Opportunity was sent to a flat region named Meridiani Planum, where the MGS Thermal Emission Spectrometer had years earlier discovered a large exposure of hematite. Opportunity landed inside Eagle Crater, only 22 meters in diameter, and immediately saw exposed bedrock. During the next few weeks, the rover's examination of that outcrop settled the long-running debate about whether Mars ever had sustained liquid water on its surface. Composition and textures showed that the rocks not only had been saturated with water, but had actually been laid down under gently flowing surface water. For six months beginning in June 2003, Opportunity examined more extensive layers of rock inside the much larger Endurance Crater. The rocks had all been soaked in water. but textures in some showed periods of dry, wind-blown deposition. A consistent environment would be sand dunes in which periodically, water would pond in the troughs. Opportunity has driven more than 3 kilometers southward through the etched terrain. The expectation is for Opportunity to continue south to Victoria Crater, which is expected to have 30-50 meters of layered sediments, expanding the timeline of our view into Mars' ancient past.

Mars Express, also launched in 2003, is a European Space Agency orbiter. The spacecraft has been returning color images and other data since January 2004. It has confirmed water ice in Mars' south polar cap and added information about how the solar wind has interacted with the Mars atmosphere. Mars Express has found traces of methane in Mars' atmosphere, suggesting that either biological or non-biological source maintaining the amount in the atmosphere. The orbiter has also mapped variations in the concentration of water vapor in the lower portion of the atmosphere. The spacecraft's ground-penetrating radar instrument is finding layers indicative of subsurface structures and has measured the thickness of the polar ice cap. Its Omega near-infrared instrument has identified clays and sulfate minerals in ancient terrains, pointing to a time when water may have lingered on the surface.

The Mars Reconnaissance Orbiter (MRO) is now in an aerobraking orbit around Mars and will begin its science mapping orbit in November. The orbiter will observe the red planet for two Earth years from a 300-kilometer near-polar science orbit. With its powerful array of advanced scientific instruments, MRO will return over ten times as much information to Earth as any previous Mars mission. Not only that, MRO will as a powerful communications and navigation link to help support future Mars spacecraft. The returned data will be used to: 1) advance our understanding of the current Mars climate, the processes that have formed and modified the surface of the planet, and the extent to which water has played a role in surface processes; 2) identify sites of possible aqueous activity indicating environments that may have been or are conducive to biological activity; and 3) thus identify and characterize sites for future landed missions.

MRO will bring a suite of instruments to bear on Mars like never before. The High Resolution Imaging Science Experiment (HIRISE) has the largest aperture of any camera to leave Earth orbit. At 30cm per pixel, it can image compelling geological features as small as a kitchen table. In addition, it is capable of producing stereo pictures. The Compact

### **Reconnaissance Imaging Spectrometer** for Mars (CRISM) uses near-infrared light to provide unprecedented hyperspectral and high spatial resolution images that will identify materials at equally high resolution. The Context Camera will deliver wide area views to help provide a context for even higher resolution images of key Mars spots provided by HiRISE and CRISM. Meanwhile, the Shallow Radar will probe into the ground to search for layers of rock and ice within 500 meters of the surface. The Mars Color Imager is a multi-color wide-angle camera that will monitor clouds and dust storms on a daily, global basis, while the Mars Climate Sounder is an infrared profiling radiometer that will detect vertical variations of temperature, dust, and water vapor in the Martian atmosphere.

Phoenix is the first in a new series of small, focused, principle investigatorled mission for NASA called Scout. Selected in 2002, the Pheonix mission will be launched in August of 2007 and will land in icy soils near the north polar ice cap of Mars. The stationary lander will operate for up to three months, while a robotic arm will literally dig into the climate record contained ice and soil while checking for organic chemicals and monitoring polar climate. The arm is designed to dig a trench up to half a meter deep and deliver samples to an onboard laboratory to analyze the samples' chemistry and physical properties. The mission will serve as NASA's first exploration of this ice-rich region and renew the search for carbon-bearing compounds, last attempted by the Viking landers. The Phoenix mission was planned and developed by a team led by a University of Arizona scientist.

Mars Science Laboratory (MSL, Fig. 8) will be the first roving analytical laboratory on Mars, carrying 75 kilograms of instruments (ten times the payload mass of the Mars Exploration Rovers) capable of definitive mineralogy and able to characterize a wide range of any organic compounds that it finds. This mission will use precision landing technologies to put the science instruments in the most scientifically exciting, but safe place. MSL is designed to operate for more than a Martian year (687 Earth days). To help scientists assess whether the landing area ever had or still has environmental con-

NASA's Mars Exploration Program plan through the end of the decade envisions a series of orbiters and landers operating in concert to search for more evidence of liquid water on Mars. Mars Express and other international missions are not shown. (Source: NASA)

# Advances of the provide of the provi

ditions favorable to life, the rover will analyze many dozens of samples scooped from the soil and cored from rocks. Instruments have been selected that could identify and inventory the chemical building blocks of life and identify features that may show effects of biological processes. MSL sets the course of future exploration in addressing the question of whether signatures of life might be preserved in the near sub-surface.

MSL will be carrying remote sensing instruments for studying the Martian abundance of chemical elements in rocks and soils. Sponsored by the Canadian Space Agency, the APXS would be placed in contact with samples on Mars to inventory the area and select candidate samples for further analysis. The Mars Hand Lens Instrument (MAHLI) is a sophisticated hand-lens and camera. It will provide scientists with close-up views of the minerals, textures, and structures in martian rocks and the surface layer of rocky debris and dust. MAHLI will carry both white and ultraviolet light sources,

"As in oceanography in the last century, our progress in understanding Mars is growing from 'what's there?' to an understanding of global processes through time and a growing ability to build and test different hypotheses."

environment and selecting the most promising locations for further exploration. MSL will have a series of instruments arrayed on its body and mounted on armatures that can inspect samples in situ, bring them inside a mini laboratory built into the body of the lander, and analyze the surrounding environment. A Mast Camera will take color images, three-dimensional stereo images, and color video footage of the Martian terrain. The camera will also be able to take high-definition video at 10 frames per second. ChemCam will fire a laser at objects within ten meters and analyze the elemental composition of vaporized materials on the surface of Martian rocks and soils. An on-board spectrograph will provide unprecedented detail about minerals and microstructures in rocks by measuring the composition of the brief glow of the resulting plasma. The Mars Descent Imager will take color video during the rover's descent toward the surface, providing a nested series of pictures, from a bird's eye view to close-ups of the local environment.

MSL's Alpha Particle X-Ray Spectrometer (APXS) that will measure the making the imager functional both day and night.

Within the rover body are the two analytical instruments that boost science measurement capabilities to a new level for Mars exploration. The Chemistry and Mineralogy instrument, CheMin, will identify and measure the abundances of various minerals on Mars. Minerals are indicative of environmental conditions that existed when they formed, including the presence or absence of liquid water. The Sample Analysis at Mars (SAM) instrument suite will feature chemical equipment found in many scientific laboratories on Earth. SAM would search for and identify a wide range of compounds of the element carbon, including methane, that are associated with life. Actually a suite of three instruments, including a mass spectrometer, gas chromatograph, and tunable laser spectrometer, SAM would also look for and measure the abundances of other light elements, such as hydrogen, oxygen, and nitrogen, associated with life.

Finally, another three instruments will measure the rover's immediate environment. The Radiation Assessment De-

tector (RAD) is designed to be one of the first instruments sent to Mars specifically to prepare for future human exploration. RAD will measure and identify all highenergy radiation on the Martian surface, such as protons, energetic ions of various elements, neutrons, and gamma rays. That includes not only direct radiation from space, but also secondary radiation produced by the interaction of space radiation with the Martian atmosphere, surface rocks and soils. Also onboard is the Russian contribution of Albedo Neutrons, DAN. By measuring the slow-down of neutrons by interaction with the hydrogen molecules in water, DAN will be sensitive enough to detect water content as low as one-tenth of 1 percent and resolve layers ice within one meter of the surface. MSL will carry a weather monitoring station provided by the government of Spain on behalf of investigators at the Centro de Astrobiología (INTA-CSIC). The Rover Environmental Monitoring Station will provide a daily report of atmospheric weather conditions on Mars. Attached to the vertical mast on the rover deck, the station will measure atmospheric pressure, humidity, ultraviolet radiation from the sun, wind speed, wind direction, and air temperature.

Mars remains a high priority for planetary exploration as our nearest neighbor with the potential for life - past, present, and future. With this handful of spacecraft, we have learned that in the distant past, Mars was more Earth-like and had water on its surface. What is emerging, is a more recent, episodic Mars, whose climate can radically change and affect where ice and potentially where liquid water may exist. Combined with the Mars missions in development, we are in the golden age of Mars exploration and are on the threshold of potentially discovering if life ever arose on a planet outside our own.

*Michael Meyer* is the Lead Scientist for NASA's Mars Exploration Program and the Program Scientist for the Mars Science Laboratory.

# **A Different Vision for Space Exploration**

On 14 January 2004, President George W. Bush outlined a new focus for NASA that has come to be called the "Vision for Space Exploration," which emphasizes the development of new human spaceflight systems capable of carrying crews beyond low-Earth orbit out to the Moon, Mars, and beyond. A year and a half later, is it time to ask whether this human-focused approach to space science and exploration is the best way to allocate our limited resources?

by Donald A. Beattie

Until a "string theorist," steeped in the arcane physics of quantum mechanics, devises a method to travel at warp speed in our universe, or parallel universes, our astronauts will have to stick close to good old friendly Earth. There will be, of course, robotic missions to the far reaches of the solar system and beyond, and humans may make voyages to destinations within the inner solar system. However, human flights will be infrequent for the simple reasons of cost, risk, and most importantly, the returns that can reasonably be expected to justify these costs and risks.

Space exploration will continue. The difficult questions to answer are: what should be the content, and what should be the pace? Arguments are always trotted out about how the human race must explore and expand its horizons just as we have done throughout recorded history. What is over the horizon? What new discoveries would be made if only we were to take the next steps? Questions such as these motivated our ancestors to take on daunting challenges that led, in many cases, to unexpected discoveries. Usually, especially during the 15th, 16th, and 17th centuries, the passion that drove explorers to travel beyond the horizon was stimulated by the anticipation of great economic gains. In those centuries, what was beyond the horizon was truly unknown.

But that was then and this is now. The major mysteries of the Earth have been solved. The world is round, almost; the composition and extent of the continents are known; we understand the workings of Earth's atmosphere; the oceans have been plumbed; and humans have explored beyond the narrow confines of Earth. In addition, using wonderfully crafted instruments located in space and on mountain tops, we have studied the universe to its earliest beginnings and its deepest mysteries are now being revealed. What is left to learn? Who would chance a prediction? Despite all we have learned so far, there will be much more that future generations will discover about the Earth and the universe. That is a certainty.

If this last statement is true, then why suggest that space exploration missions carrying men and women will be infrequent? The answer to that question is posed above. What will be the motivation, why send humans to explore the solar system rather than use robots that are becoming more capable every day? Or should it be a combination of robots and humans? There is no argument that human explorers, if provided with the required resources, can carry out activities that a robot can not, or do it more completely, or faster, or respond better to unforeseen problems. But what are these problems that, at great cost and risk, we would ask astronauts to try and solve on a distant planet?

In July 2005, *Science* magazine published: "125 Questions: What Don't



This approximate true color image of Saturn and its Rings, captured by the Cassini spacecraft, are examples of planetary exploration detail that would not be possible without robotic space exploration. (Source: NASA/JPL/Space Science Institute)

We Know?" The list does not include questions dealing with societal problems but is "...a survey of our scientific ignorance, a broad swath of questions that scientists themselves are asking." Does this list include all the important questions? Perhaps not, but it is a good start. The first thing that will strike a reviewer of the list is that none of the questions will be answered by sending either robots or astronauts to the Moon. Reinforcing the assertion that there is an absence of important scientific discoveries still to be made on the Moon, some may recall that plicate what we accomplished thirty-eight years ago, let them try. The Moon will not become a military "high ground," and, if we continue to accept the challenge to explore space, we will not be left behind in the technological race, as some fear.

Can the four reasons listed above pass a test of close analysis? Reason 1 assumes that there will be many robotic and human space missions that would be serviced by extracting useful fuels from lunar material. Thus, it will warrant the huge expenditures to establish the infrastructure necessary to mine lunar mate-

"In July 2005, Science magazine published: "125 Questions: What Don't We Know?" ... The first thing that will strike a reviewer of the list is that none of the questions will be answered by sending either robots or astronauts to the Moon."

in 1977, after continuously monitoring the geophysical stations still operating at the Apollo landing sites, NASA chose to turn them off. The reason: no unusual events being recorded were worth the cost of \$1 million a year to continue collecting data.

Thus, NASA's near-term focus on returning to the Moon must be justified on grounds other than answering important scientific questions. In brief, NASA describes these reasons as follows: 1) utilize lunar resources, such as oxygen found in lunar minerals, to fuel space probes launched from the Moon; 2) explore a resource mined on the Moon for use on Earth; 3) learn how to live on another "planet" in preparation for sending astronauts to Mars; and 4) use the Moon as a testing ground for technologies needed for future solar system exploration. NASA has stated that each of these four reasons is an important objective worthy of the cost to proceed. Some believe there is another reason to return to the Moon. China and Russia say they "plan" on sending "taikonauts" and cosmonauts to the Moon, and may build bases. If other countries want to spend their resources to durial, process it, then collect and store the fuel. The argument for why one would want to fuel space missions on the Moon is justified by the fact that the "gravity well" that must be overcome to launch a space mission is much less than launching from Earth or Earth orbit. Therefore, one needs less fuel for a given mission and, perhaps, a smaller launch system.

True, but where is the cost breakover point compared to launching from Earth where all the facilities are already in place? How many launches, how much fuel must be manufactured, to make it worthwhile? Refueling and launching rockets is a difficult and dangerous job requiring a complex infrastructure. We launched Apollo lunar modules from the Moon for rendezvous in lunar orbit without a hitch because each lunar module was a fully contained spacecraft. Refueling on the lunar surface was not necessary. A launch complex on the Moon will require, at some scale, all the facilities found on Earth. In addition, the launch will have to be carried out with some or most workers doing their jobs in space suits. It also requires that the spacecraft launched from

Earth, to be fueled on the Moon, must land on the lunar launch pad or face the added problem of transporting it to the launch site. None of these requirements are impossible; however, does a detailed analysis, using reasonable assumptions, exist of the cost-benefit of a combined Earth-Moon launch sequence? Lacking such an analysis, proposing to process lunar material on the Moon to augment solar system exploration is not justified.

Reason 2 assumes that there is a resource on the Moon that is so valuable that the cost of developing the infrastructure to mine, process, and deliver it to Earth is outweighed by its value on Earth. The only resource thus far identified that may have this potential is He-3. By applying many helpful assumptions, an economic model indicates it would be possible to mine He-3 on the Moon and return it to Earth for useful applications; the most important being as a fuel to generate electric power in a fusion reactor. One of the most challenging assumptions in the model, in order for the enterprise to be economically viable, is that mechanical systems can be designed to operate automated and occasionally tended by astronauts, "indefinitely," in the hard vacuum of space. In addition, the equipment must process huge quantities of lunar soil while every lunar cycle subjects the equipment to temperature swings of plus/minus 250<sup>0</sup> F. All moving parts will have to incorporate designs never before required for mining equipment. To pass the economic test a lot of Moon dirt, hundreds of square kilometers, must be processed to obtain enough He-3, found at perhaps ten parts per billion in the soil, to fuel a large number of fusion reactors on Earth.

In addition to the problems that make the forecast positive economics questionable, a fusion reactor that would burn He-3 does not exist. Research to design and build fusion reactors that would be competitive with conventional electric power generators has been underway, without success, for over thirty years. It is a very difficult technology to master. Recently, a \$12 billion dollar fusion experiment, ITER, was initiated that will not be operational for many years. At the end of that time, if the experiment achieves its goals, a reactor that could produce electricity at competitive rates still will not exist. To further complicate the possibility that He-3 fusion reactors will ever be built, other fuels can be found on Earth that can be used in fusion reactors. We do not need to go to the Moon for fuel. Any advantage deriving from a fusion reactor fueled by He-3 is offset by the difficulty of obtaining the fuel. When all the assumptions and unknowns are added up, the economic viability of mining the Moon for He-3 make this reason for returning to the Moon suspect.

Reason 3 is predicated on the need to learn how astronauts could live and work on the Moon, as training to live on Mars in the future. The first two reasons for not returning to the Moon, discussed above, are in play with this goal. Lunar resources would need to be mined, processed, and stored so that the logistics of supplying a lunar base would be reduced. This goal would also serve as a technological precursor to using raw materials found on Mars if a base were built there. Again, one must ask the important remaining question: Why would humans want to "live" on the Moon? As there are no major scientific questions to be answered, and using lunar resources for any practical application is highly questionable from a cost-benefit perspective, there is no need for a lunar base. Next, is there a need for a Mars base where astronauts would have to utilize Mars resources in order to survive? Can you imagine that a first-time human mission to Mars would ever be planned that would require using Mars raw materials for the fuel to return home or oxygen and water to sustain life while on the surface? Besides few, if any, astronaut missions to Mars may ever be needed because extensive robotic exploration will come first. The answer to the only important question may be in hand without direct human intervention.

Why might only a few, or no human missions to Mars be required? Of the 125 questions mentioned above, only one may be answered by exploring Mars:



Reason 4, using the Moon as a testing ground for technologies or systems before sending them on the real mission, will slow and increase the cost of exploration, not enhance it. Each solar system body, be it a planet, moon, asteroid, or comet, is sufficiently different from the other that every mission must be tailored to the specific objectives of the mission. To use resources to first test systems on the Moon, and then modify them to explore another solar system body, has not been shown to provide a positive costbenefit. We have already photographed, landed, moved about on the surface, and conducted sophisticated analyses of several bodies in the solar system. From each we have learned a great deal about what works and what doesn't work. Taking a detour to the Moon to test future systems will not be a shortcut to success.

Now that we have saved a lot of time and resources by not sending missions back to the Moon, what are the goals and objectives of this different vision of space exploration? The 1958 Space Act still defines the vision of what Congress expected NASA to accomplish; language in the Act is not skewed to a single objective. By freeing up funds now required to return to the Moon, NASA's traditional programs that face cancellation or cutbacks can proceed. Within NASA budgets the competition for limited science funds is intense. Funding added to one line item will usually result in the reduction of another line item. This is where future congresses and administrations must exercise great discipline. Special interest earmarks that do not advance fundamental research must be rejected. Funding for federally supported research will



The Apollo Lunar Surface Experiment Package, deployed on the lunar surface during Apollo 16, comprised a set of geophysical measurement instruments that were designed to run autonomously after astronaut installation. (Source: NASA)



Pictured here is an artist's conception of a lunar mining facility that could be used to harvest oxygen and manufacturing metals such as iron, aluminum, magnesium and titanium from the volcanic soil of the eastern Mare Serenitatis. (Source: Pat Rawlings/NASA)

never be sufficient to satisfy all the researchers waiting in line to conduct "very important" programs. Other agencies, including National Science Foundation, the National Institutes of Health, the Department of Energy, and the National Oceanic and Atmospheric Administration, contend for federal science funds in what has become, essentially, a zero-sum funding environment. In all cases, selecting a course of scientific endeavor must show that the approach chosen has the promise of being of greater incremental benefit than a different, less costly approach. In this regard, NASA space exploration programs compete with all other science programs funded by Congress.

What must be done is that all federally funded science programs should be prioritized, one against the other. The National Academies of Science (NAS) should perform the prioritization under contract with Congress with assistance from each affected agency. Once established, priorities should only be changed in the event of a major, unforeseen event that Congress and NAS agree should take precedent over previously agreed to priorities. As a starting point, prioritization should be based on the "125 Questions: What Don't We Know?" or a similar set of questions developed by the NAS. Within each question, specific programs and experiments should be defined and prioritized. For each program and experiment, a careful schedule and cost projection should be developed. Those space exploration programs that survive this rigorous analysis can then be included in NASA's budgets.

While prioritization is underway (probably a two year effort), all science does not come to a halt. There will be many new and important scientific investigations to fund that will be relatively non-controversial, as well as ongoing programs. However, regardless of the scientific discipline, spending resources on second or third-order priority investigations should be avoided. Many of the 125 high priority questions deal with the biological and earth sciences. There are, in addition, some that can be best addressed by space systems. These include: How do planets form? What is the nature of gravity? What drove cosmic inflation? It

seems clear that there will be a need to build and operate a next generation Hubble telescope and other types of observatories including the currently scheduled James Webb Space Telescope. These telescopes and observatories must be built to be "robotic and astronaut friendly" so that their lifetimes and capabilities can be extended and upgraded at minimum cost.

Even after a rigorous prioritization of space programs is accomplished, some will continue to declare that we must send astronauts back to the Moon and on to Mars because there will be many unexpected discoveries. After all, that is what exploration is all about. If you knew what you would find, then why go? Despite such assertions, it is possible to discuss what we won't find. The Periodic Table helps to define this issue. We will not find any new elements on the Moon or Mars, nor will we find any new minerals that would be so valuable that mining them for use on Earth would be cost effective. We already have an excellent understanding of the history of the Moon. Learning more about Mars will appeal to some planetologists but, in the larger scheme of understanding the evolution of the solar system, will not result in any breakthroughs that will have a profound impact. Mounting a detailed exploration program for Mars, if it should ever come to pass, will have to await the day when resources for such exploration are more readily available.

For NASA, this new vision will require an adjustment no more painful than the restructuring currently underway. Making use of the astronaut corps during this period of redirection may pose the biggest problem. Presently, between 2010 when the shuttle is scheduled to be retired and the time when the Crew Exploration Vehicle (CEV) is available, perhaps 2014, there will be no missions to launch astronauts or payload specialists except on the Russian Soyuz. A lesson learned: the second class of scientist-astronauts. selected in 1967 for Apollo missions that were subsequently canceled, waited twenty years for a shuttle flight. That was not a happy time at the Johnson Space Center. Some walked away rather than wait for an assignment. Every effort should be made to avoid having individuals in the astronaut corps leave NASA because they foresee a long wait before their next flight. However, there is a way to keep current and future astronauts involved in important work.

A decision must be made quickly to better utilize the \$100 billion dollar investment we, and our fifteen partners, have made in the International Space Station. The Space Shuttle should not be retired in 2010 in spite of the high cost and risk of each launch. The Shuttle is the only way to keep the Space Station fully supplied. The Russian Soyuz and Progress vehicles, and the CEV and ESA Automated Transfer Vehicle (neither of the last two yet operational) have only a limited capability to service the Space Station. Crews of six or more are needed on a continuing basis to provide the housekeeping and to carry out scheduled experiments. Continuing to operate the Shuttle will take pressure off the ambitious development schedule for the CEV; this should be a welcome respite for NASA managers and contractors. Past

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experience demonstrates that new manrated vehicles encounter unforeseen problems along the way. Although the CEV is touted as incorporating many heritage systems, they will be performing together in a new operational environment.

If the Shuttle is retired in 2010 it means that the centrifuge, built by Japan for \$500 million dollars, will never reach orbit. Originally, it was considered the most important experimental facility that would be docked to the Space Station. If for some reason problems are encountered transporting and attaching the remaining elements on the manifest, without the Shuttle there will be no alternative vehicle available to complete construction. Some of the International Space Station elements have been on orbit for eight years and by the time scheduled construction is completed they will be twelve years old. Space systems eventually wear out. Components, such as the solar arrays, have limited lifetimes and must be replaced if the Space Station is to operate efficiently. Without the Shuttle, it will be difficult or impossible to maintain the facility if there is a major system or element failure. We have already spent some \$2 billion dollars after the Columbia accident

to make each shuttle launch less risky and more improvements are scheduled. Why walk away from that investment? One would hope the Space Station will continue to operate well past the 2010 date and in order for this to happen maintenance must continue. Until (and if) the CEV is available in 2014, crew size will be restricted. The Shuttle is by far the best asset available that will assure continued, safe operation.

This "Vision of Space Exploration" is very different from that currently being pursued. If selected as the better way to proceed, the impact it will have on NASA as an institution will be positive. It will require a change in some funding levels for the next two years. After that, NASA can continue down a path of exciting and rewarding programs that takes full advantage of all the agency's capabilities.

Donald A. Beattie is a former NASA engineer who has also worked with the National Science Foundation and the Department of Energy. He currently works as a private consultant. He is also the author of History and Overview of Solar Heat Technologies and Taking Science to the Moon: Lunar Experiments and the Apollo Program.

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# 17<sup>th</sup> AAS/AIAA Space Flight Mechanics Meeting

January 28 – February 1, 2007 Hilton Sedona Resort & Spa, Sedona, Arizona

The seventeenth annual AAS/ AIAA Space Flight Mechanics Meeting will be held at the Hilton Sedona Resort & Spa in Sedona, Arizona, from January 28 through February 1, 2007. This event is co-sponsored by the American Astronautical Society (AAS) and the American Institute of Aeronautics and Astronautics (AIAA), and organized by both the AAS Space Flight Mechanics Committee and the AIAA Astrodynamics Technical Committee.

Papers are being sought that pertain to all areas of astrodynamics. Topics of interest include, but are not limited to, the following:

- Orbital dynamics, perturbations, and stability
- Orbit determination and tracking
- Spacecraft guidance, navigation, and control
- Trajectory design and optimization
- Satellite constellation design and formation flying
- Atmospheric density modeling
- Earth orbital, asteroid, and planetary mission studies
- Libration point trajectories
- Low thrust mission and trajectory design
- Artificial and natural space debris
- Planetary defense
- Orbital rendezvous and proximity operations
- Attitude dynamics, determination, and control
- Attitude and payload sensor calibration
- Dynamics and control of large space structures and tethers
- Reentry flight mechanics

Updated and additional information on the conference will be posted at the AAS Space Flight Mechanics Committee website: **www.space-flight.org** 

### **Special Sessions**

Proposals are solicited for special sessions such as panel discussions, invited sessions, workshops, and mini-symposia. Potential special session organizers should submit a proposal to the Technical Chairs. For a panel discussion, this proposal should include a title of the discussion, a brief description of the topics to be discussed, and a list of the speakers and their qualifications. For an invited session, workshop, or mini-symposium, the proposal should consist of the title of the session, a brief description of its significance, and the extended and condensed abstracts for each talk to be included.

### **Information For Authors**

Papers will be accepted on the basis of **extended abstracts**. Authors are required to use an automated web-based system for submitting the extended abstract, a condensed abstract, and author information. If authors are unable to use the automated web-based system, they should contact the Technical Chairs for instructions on submitting papers by Email. The web site for submitting this information is: **www.pxinet.com/aas** 

Please note that the **extended ab**stracts are due by October 1, 2006.

The information required is as follows:

- 1) Title of the technical paper
- The name, affiliation, postal address, telephone number(s), and E-mail address of each author
- 3) The text of the extended abstract, having a length of 500-1000 words and containing supporting tables and figures. The extended abstract should provide a clear and concise statement of the problem addressed and the results obtained. Submissions without

extended abstracts will not be considered. The extended abstract must be uploaded in the form of a PDF file.

 A condensed version of the abstract (100 words maximum) to be included in the printed conference program. Avoid using symbols and Greek characters in the short abstract. The short abstract must be pasted into the box provided on the web page.

Notification of acceptance will be sent to the authors via E-mail by November 1, 2006. Author instructions will be sent by E-mail and also placed on the website: **www.space-flight.org** 

Final manuscripts are required and must be electronically uploaded to the website prior to attending the meeting. Authors are also required to supply their Session Chairs with a printed copy of their paper along with a short biography of the presenter before the meeting. A no paper-no podium rule will be in effect for all presentations. Authors whose papers are not uploaded to the website or are not available in printed form at the time of the meeting will not be allowed to present their papers. After the meeting, all authors will have an opportunity to upload revised versions of their papers for publication in the conference proceedings.

Please note that **electronic** formats (e.g. PowerPoint, Adobe PDF) will be required for all technical presentation charts briefed at this conference.

### **Breakwell Student Travel Award**

The AAS Space Flight Mechanics Committee also announces the John V. Breakwell Student Travel Award. This award will provide travel expenses for up to three U.S. and Canadian students presenting papers at this conference. The maximum coverage per student is limited to \$1000. Further details and applications may be obtained at: **www.spaceflight.org** 

# Warning - Technology Transfer Considerations

Prospective authors are reminded that technology transfer guidelines have substantially extended the time required for the review of abstracts and completed papers by private enterprises and government agencies. These reviews can require four months or more. It is the responsibility of the authors to determine the extent of approval necessary for their papers to preclude late submissions and paper withdrawals.

### All material (cover page, abstracts, etc.) should be sent to each of the two Technical Chairs below:

AAS - Dr. Maruthi R. Akella ASE/EM Dept WRW 414, MC: C0600 The University of Texas at Austin Austin, TX 78712 Ph: 512-471-9493 Fax: 512-471-3788 makella@mail.utexas.edu

AIAA - Dr. James W. Gearhart Orbital Sciences Corporation 42920 Maplegrove Court Ashburn, VA 20147 Ph: 703-406-5818 Fax: 703-406-5705 jpgearhart@adelphia.net gearhart.james@orbital.com

### For other questions regarding the conference, please contact one of the General Chairs below:

AAS - Dr. Robert H. Bishop The University of Texas at Austin Dept of Aerospace Engineering and Engineering Mechanics, Austin, TX 78712 Tel: 512-471-4258 Fax: 512-471-3788 rhbishop@mail.utexas.edu

AIAA - Alfred J Treder Barrios Technology 28327 183rd Ave SE, Kent, WA 98042 Work: 253-639-5101 Cell: 206-818-5732 Home: 253-630-3166 altreder@earthlink.net

# **AAS Honors Japanese Student**

he 25th International Symposium on Space Technology and Science (ISTS) was held June 4-June 11, 2006 in Kanazawa, Japan. The theme was "Space Exploration for a Peaceful Planet Earth!" Approximately 800 participants from 18 countries submitted more than 600 oral presentation and poster session papers. The Opening Ceremony included opening comments from Prof. Yasunori Matogawa, from ISAS (JAXA), as General Chair of the 25th ISTS Organizing Committee, Congratulatory addresses from: Mr. Masanori Tanimoto, Governor of Ishikawa Prefecture; Mr.Tamotsu Yamada, Mayor of Kanazawa City; Professor Tetsuhiko Ueda, President of the Japan Society for Aeronautical and Space Sciences; and Prof. Peter M. Bainum. Howard University and the AAS, on behalf of the Overseas Organizing Committee. On June 7, 2006, five different student awards were presented in the Student Commendation Ceremony including the AAS Award for the Most Innovative Application of Space Technology. Various cultural events were offered during the week including a technical tour to three different local industries. An opening welcome reception was

held on Monday evening and a farewell banquet terminated the activities on Friday evening, both with spectacular entertainment. Key participants from the USA included Ms. Patricia G. Smith, Associate Administrator, FAA, who presented a Keynote Speech on "Preparing for Private Human Space Flight", and Mr. William Jordan, NASA representative at the US Embassy in Tokyo, describing the US National Space Program and updates on the International Space Station.



Dr. Peter Bainum presents Naritoyo Shibata from Kyushu University the AAS Award for his paper "Orbital Transfer of a Tethered System Using Pitch Motion Control through Tether Length Variation." (Source: Peter Bainum, AAS)

# **30<sup>th</sup> AAS Guidance and Control Conference**

### February 3-7, 2007 Beaver Run Resort, Breckenridge, Colorado

**Greetings** from the Rocky Mountain Section of the American Astronautical Society!

The 30th Annual Guidance and Control Conference will be held February 3-7, 2007 at the beautiful Beaver Run Resort in Breckenridge Colorado. We are committed to inviting the best papers and presenters to this conference, please submit abstracts for potential papers to the contacts listed. The deadline for abstract submission is October 31, 2006.

The conference will have the following sessions. Their themes are listed as well as the session chairperson to contact for abstract submission. Sessions 9 and 10 will not be ITAR-restricted, whereas Sessions 1 through 8 are the traditional international sessions.

Session 1 "Advances in Guidance and Control" Some projects require innovative G&C solutions that are outside the realm of conventional thinking. The papers in this session will focus on the latest in theoretical developments, cuttingedge hardware, unique mission possibilities, system architecture, autonomous operations, and system modeling and testing. Contact: Ian Gravseth (igravset@ ball.com)

Session 2 "Technical Exhibits" The Technical Exhibits Session is a unique opportunity to observe displays and demonstrations of state-of-the-art hardware, design and analysis tools, and services applicable to advancement of guidance, navigation, and control technology. Associated papers, not presented in other sessions, are also provided and can be discussed with the author. The latest commercial tools for GN&C simulations, analysis, and graphical displays are demonstrated in a hands-on, interactive environment, including lessons learned and undocumented features. This session takes place in a social setting. While an excellent free buffet is served, conference attendees can interact with technical representatives and authors. The innovative technology can be discussed directly with design engineers. Contact: Alex May (alexander.j.may@lmco.com) or Rick Jackson (ricski\_jackson@yahoo.com) or Jay Brownfield (jay.brownfield@ honeywell.com) or Marv Odefey (modefey@MSN.com) or Joe Vellinga (joseph.m.vellinga@lmco.com)

Session 3 "International Lunar Ambitions" NASA's Vision for near-term human and robotic exploration of the Moon, combined with international Lunar exploration initiatives, has led to an unprecedented realignment of resources for returning to the Moon. This is due to scientific interest in the Moon itself and, also, as a springboard for future deep space human and robotic exploration to other destinations, like Mars. The unique and challenging guidance, navigation and control aspects of very ambitious lunar missions, such as the Crew Exploration Vehicle (CEV)/Lunar Surface Access Module (LASM), the Lunar Reconnaissance Orbiter (LRO), the Japanese Selene spacecraft or the ESA SMART-1 mission, are addressed in this session. The topics covered include launch, rendezvous, sample return, entry-descent-landing and surface operations. A broad range of papers will be presented covering design, analysis, and operational solutions. Contact: Mary Klaus (mary.a.klaus@lmco.com)

Session 4 "GN&C Challenges of Microsats" The success of recent Micro-Satellite missions, combined with DoD interest in smaller vehicles to host payloads for launch-on-demand, responsive space missions, has created a thriving market for Micro and Nano satellite vehicles. Packing "large spacecraft" functionality into these smaller spacecraft buses has required significant technology advances. This session will address the challenge of obtaining traditional GN&C performance utilizing miniaturized sensors, integrated avionics packages, and vehicle control with limited actuator capability. Contact: Mike Drews (michael.e.drews@lmco.com) or Mike Osborne (michael.l.osborne@ lmco.com)

Session 5 "Spacecraft Constellations and Formation Flying" Recent and proposed space missions with multiple spacecraft are becoming more prevalent in recent years. This is due, in part, to the desire for synergistic science by exploiting multiple sensor packages distributed across independent spacecraft. There has also been significant study toward spacecraft constellations for interferometry and segmented telescope applications. This session address aspects of the conceptual design, simulation, maintenance strategy, and implementation challenges and lessons learned, where applicable, of systems of spacecraft used in both loosely and tightly coupled constellations. Contact: Dave Chart (david.a.chart@lmco.com)

Session 6 "Advances in GN&C Components" Many advances in sophisticated and complex GNC solutions are achieved through innovative improvements in component capabilities. This session will focus on the most cutting edge developments in GNC components with an emphasis on their properties and potential impacts for the GNC user. Papers are encouraged that are tutorial, theoretical, experimental, and/or application oriented which address future subsystem architecture/modeling, core advances in technological development, and uses/ drawbacks of component hardware. Contact: Christine Mollenkopf (cmollenk@ ball.com) or Chris Robb (crobb@ball.com) Session 7 "Recent Experiences" Lessons learned through experience prove most valuable when shared with others in the G&C community. This session, which is a traditional part of the conference, provides a forum for candid sharing of insights gained through successes and failures. Past conferences have shown this session to be most interesting and informative. Contact: Jim Chapel (jim.d.chapel@ lmco.com) or Shawn McQuerry (shawn.c. mcquerry@lmco.com)

Session 8 "Unmanned Aerial Vehicle Guidance and Control" Unmanned Aerial Vehicles have proven to be highly effective for long-dwell applications to reconnaissance, remote sensing for natural resources, and national border patrol. This session explores the GN&C aspects of these applications, including airspace management, remote piloting, autonomous operations, and recent experiences. Contact: Bill Frazier (wfrazier@ball.com)

Session 9 "U.S. Space System Research: Autonomy and Innovations in Guidance and Control – US ONLY" U.S. government laboratories and agencies sponsor research and development for

Continuted on page 22

## AAS and AIAA Sign Cooperative Agreement Global Space Exploration Seminar to be First Joint Activity

The American Astronautical Society and the American Institute of Aeronautics and Astronautics (AIAA) recently signed a Memorandum of Agreement to collaborate in the development and planning for international activities and programs of each organization.

"Both AAS and AIAA share a commitment to strengthen the global space program. It makes sense to combine our unique capabilities through cooperation with international space organizations, and bring comprehensive, value-added perspectives and programs to the space community. We look forward to a growing, productive relationship with AAS," stated Vincent Boles, AIAA vice president, international.

The agreement includes co-sponsorship of certain events, representation on each other's international committees and promotion of activities and events in the organizations' respective magazines, Space Times and AIAA's Aerospace America.

"The AAS and AIAA have cooperated for many years in organizing first class technical meetings. I'm delighted that we will now work closely together to promote and expand international dialogue and collaborative activities on current and future space endeavors. We are already actively engaged on our first initiative that will address human and robotic space exploration activities worldwide," said Lyn Wigbels, AAS vice president, international.

The first activity by AAS and AIAA under this new agreement is a series of events to highlight global space exploration objectives, plans and industrial capabilities, and develop a single integrated database of space exploration activities worldwide.

Organized in conjunction with George Mason University, "Contributions to Space Exploration: Global Objectives, Plans and Capabilities" will be launched with a public seminar November 1-2, 2006, at the George Mason University, Arlington Campus, Virginia. It will highlight the important role of international cooperation and feature presentations by numerous space agencies.

The series also will include a meeting of a synthesis group to develop a summary document of national exploration plans, an invitation-only workshop to be held in early 2007 to review the summary and discuss next steps, and a written report on the summary and workshop findings.



Left to Right: Jim Kirkpatrick (AAS Executive Director), Lyn Wigbels (AAS VP International), Vince Boles(AIAA VP International), and Bob Dickman (AIAA Executive Director) sign the MOA. (Source: AIAA)

# Space Times Article Submission Guidelines

We accept feature articles (1500-3000 words), op-eds (500-1500 words), and book reviews (600 words or less). Exceptions to these lengths may be possible and should be discussed with the editor. The editor and author will agree on a length at the time an assignment is made.

Articles can cover virtually any topic involving space science, technology, exploration, law, or policy. We welcome articles that touch on issues relevant to the civil, commercial, and military and intelligence space sectors alike.

Articles should be written for a well-educated audience that has great interest in space topics but may not necessarily be familiar with your specific topic.

We are a magazine, not a technical journal. Articles should be written in active voice and should explain technical concepts clearly. Tone should lean more toward conversational rather than stiff and formal. We do not include references with articles.

Deadlines occur six to seven weeks before the first month of the issue in question (e.g., ~Jan. 15 for the March/April issue). Exceptions are possible if discussed with the editor.

Articles should be submitted in Microsoft Word format, Times New Roman font. No need to worry about other formatting specifics – we'll take care of the rest in the editing process.

Authors should provide with their articles: a title, a "subtitle" of one or two sentences summarizing the idea of the article, sub-heads within the article that provide separations between the major sections of the article, and an author biography of one to two sentences to appear at the end of the article. You should also send a mailing address so we can send you complimentary copies of the issue in which your article appears.

Authors are encouraged but not required to submit photos or other visual supports for their articles. Suggestions for photos or visuals are also welcome. Photos need to be of high resolution (at least 300 dpi) and can be in JPG, TIF, or GIF formats. We must receive permission from photo owners to use photos, so please provide proof of permission or contact info for the photo owner if you haven't already secured permission.

A few style pointers:

- Units of measurement should be conveyed in metric, not English, terms.
- Acronyms should be used sparingly, and only when a term is used several times.
- Names of specific spacecraft (e.g., *Columbia*) should be italicized. General spacecraft names (e.g. space shuttle, Delta) should not.
- Numbers one through one hundred should be spelled out.

Contact: Jonathan Krezel, editor (jonathan.krezel@gmail.com).

### **30th AAS Guidance and Control Conference** (Continued from page 21)

future air, space and interplanetary missions. These missions will incorporate cutting-edge technologies to achieve operational objectives. Technologies will incorporate advancements in autonomous operations, platform attitude and navigation, and payload line-of-sight control. This session will be open to and attended by U.S. citizens only. Contact: James McQuerry (jmcquerr@ball.com) or Arlo Gravseth (Arlo.Gravseth@L-3com.com)

Session 10 "U.S. Space Initiatives – US ONLY" The United States is developing technological solutions to a variety of Commercial, Civil and Defense problems. Areas of development include exploration, remote sensing, planetary science, and innovative air and space platform configurations. This session will provide a forum to present concepts and solutions in an ITAR free environment. This session will be open to and attended by U.S. citizens only. Contact: James McQuerry (jmcquerr@ball.com) or Brent Abbott (brent.abbott@Honeywell.com)

We look forward to seeing you at the conference!

*Heidi Hallowell*, 2007 Conference Chair, Ball Aerospace & Technology Corp. (303-939-6131), and *Jay Brownfield*, Rocky Mountain Section Secretary, Honeywell Defense & Space (303-681-3316)

### AAS Welcomes Our Newest Corporate Member



For information on becoming a corporate member, visit www.astronautical.org or call 703-866-0020.

# **AAS Events Schedule**

October 17–19, 2006 **\*Short Course**  *"The U.S. Government Space Sector"* George Mason University Arlington, Virginia 703-866-0020 www.gmupolicy.net/space

November 1–2, 2006 \*AAS/AIAA Seminar

"Contributions to Space Exploration: Global Objectives, Plans, and Capabilities" George Mason University Arlington, Virginia 703-866-0020 www.astronautical.org

November 14–15, 2006 AAS National Conference and 53rd Annual Meeting

*"The Man+ Machine Equation"* Pasadena Hilton Pasadena, California 703-866-0020 www.astronautical.org

January 28–February 1, 2007 \*AAS/AIAA Space Flight Mechanics Winter Meeting Hilton Sedona Resort & Spa Sedona, Arizona 703-866-0020 www.space-flight.org February 3–7, 2007 **30th AAS Guidance and Control Conference** Beaver Run Resort Breckenridge, Colorado 703-866-0020 www.aas-rocky-mountain-section.org

March 20–21, 2007 **45th Robert H. Goddard Memorial Symposium** The Inn & Conference Center by Marriott University of Maryland University College Adelphi, Maryland 703-866-0020 www.astronautical.org

May 16–18, 2007 **\*11th International Space Conference of Pacific-basin Societies (ISCOPS)**  *"Space Exploration for the 21st Century"* Beijing, China 703-866-0020 www.astronautical.org

August 19–23, 2007 **\*AAS/AIAA Astrodynamics Specialist Conference** Mission Point Resort Mackinac Island, Michigan 703-866-0020 www.space-flight.org

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\*AAS Cosponsored Meetings

### **AAS National Conference and 53rd Annual Meeting**

"The Man + Machine Equation"

November 14-15, 2006 Pasadena Hilton, Pasadena, California

Coming soon on the AAS Web Site - program details, online registration and information on the new Student Poster Contest.





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