RocketSTEM

Vol. 3 • No. 3 • July 2015 • Issue 12

Pilot your own mission to space with Kerbal

Apollo 15's debut of the lunar rover

What happens when a launch goes wrong

Al Worden on the honor of being an astronaut

New Horizons bringing Pluto into sharp focus

SPACE IS HARD

The past nine months have been difficult ones for rocketry. Multiple failures of Russian launch vehicles, the loss of SpaceShipOne during a test flight, the Antares rocket with the Orb-3 mission falling back to the launch pad in a fireball, and most recently, the disintegration of the SpaceX Falcon 9 rocket carrying a resupply mission to the International Space Station.

There is no getting around it. Even after five decades of launching satellites and humans into space, the truth remains that as we strive to become a space-faring species, we are pushing against the extreme edges of our technological prowess. We are creating machines to be able to perform at a level previously undreamt, while making demands of metals and other materials to be thinner and lighter, yet also stronger than ever before achieved. We push our machines just to this side of impossibility, and occasionally even beyond.

Humanity has always been an inquisitive species with an innate desire to explore the unknown. With that comes failure and disaster from time to time. But what defines us is our ability to look past our flaws, to overcome our mistakes, and to keep pushing those boundaries just a little bit further with each new attempt.

In this issue of RocketSTEM we bring you both success and failure. The success of the previously untested Lunar Rover sent to the Moon that carried the Apollo 15 astronauts further than any moonwalker before. And, of course, the failures of the above mentioned rocket launches.

But rather than tell you how hard it is to build and launch a spacecraft, we invite you to try for yourself. Kerbal Space Program is a game that is simple enough for a kid, yet advanced enough for engineers at NASA, JPL, and SpaceX to enjoy playing it too.

Download the game and run your own space agency. Just don't be discouraged when your first rocket explodes upon launch.

A Falcon 9 first stage approaches the barge, Just Read the Instructions, in the Atlantic Ocean after successfully launching CRS-6 to the International Space Station in April. SpaceX is striving to successfully land the first stage of their rockets in order to be able to refurbish them for future launches. Credit: SpaceX

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RocketSTEM • July 2015
Vol. 3 No. 3 Issue 12 (ISSN: 2326-0661)

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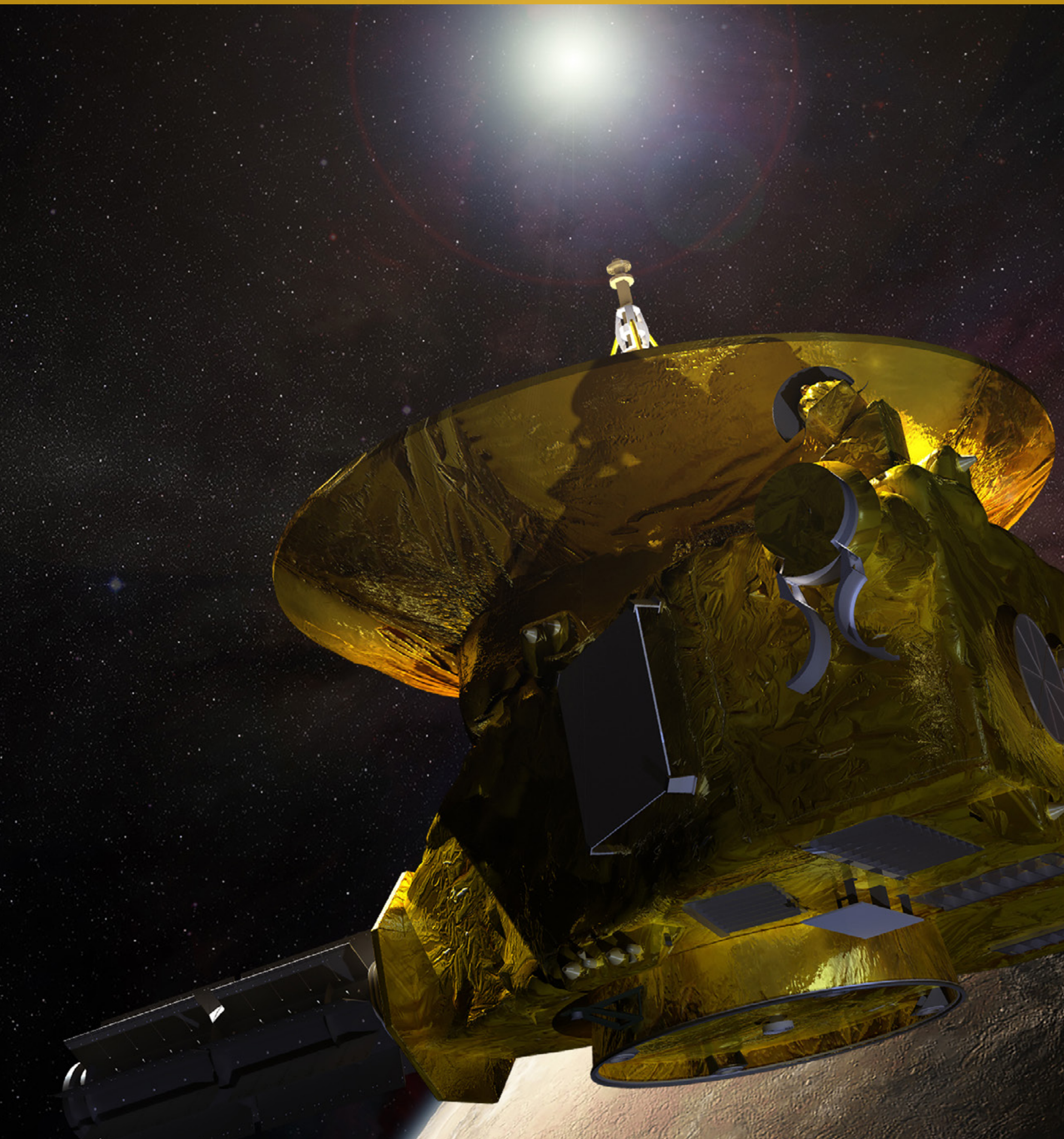
Artist's concept of the New Horizons spacecraft encountering Pluto and its largest moon, Charon, in 2015.
Credit: Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute (JHUAPL/SwRI)



New Horizons

Pluto garners the spotlight

By Amy Thompson

Nine years ago, in 2006, NASA launched the New Horizons spacecraft to the outer reaches of the Solar System in order to study the Pluto system.

New Horizons is the fastest spacecraft ever launched, and has traveled more than three billion miles to reach its primary target: Pluto. The flyby of the Pluto system on July 14 will complete our initial exploration of the Solar System while opening the door to an entirely new realm of mysterious small planets and planetary building blocks in the Kuiper Belt.

Reaching the Kuiper Belt, or the "third" zone of our Solar System — a region beyond the inner, rocky planets and outer gas giants — has been a priority for years, as it holds building blocks of our Solar System that have been stored in a deep freeze for billions of years.

Pluto, the largest known body in the Kuiper Belt, offers an extensive nitrogen atmosphere, complex seasons, strangely distinct surface markings, an ice-rock interior that may harbor an ocean, five moons. And that's just what we know.

The flyby will also cap a

five-decade-long era of solar system reconnaissance that began with Venus and Mars in the early 1960s, continuing through first looks of Mercury, Jupiter and Saturn in the 1970s and Uranus and Neptune in the 1980s. The July 14 flyby of Pluto will occur 50 years to the day after humans first explored Mars with NASA's Mariner 4 on July 14, 1965.

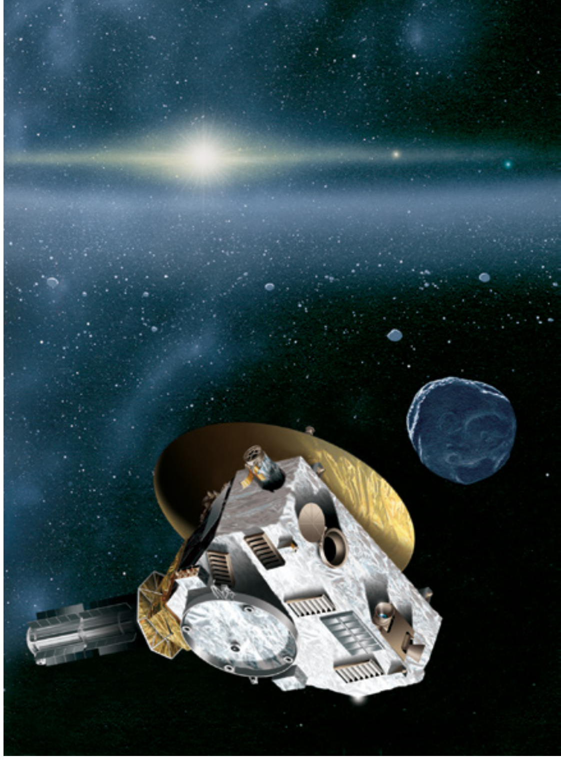
The Pluto system is unique in that it contains the only binary planet system in our Solar System. Pluto and its largest moon Charon are what scientists refer to as a double-dwarf system. Pluto is currently classified as a dwarf planet; while Charon is technically labeled a moon, both bodies orbit the same point in space—a point that isn't within the circumference of either body.

Just like the Earth and the moon, Pluto and Charon are tidally locked in an orbital dance. The two orbit like unbalanced weights on a dumbbell, each pulling on the four smaller moons—Nix, Styx, Hydra, and Kerberos—that orbit the pair.

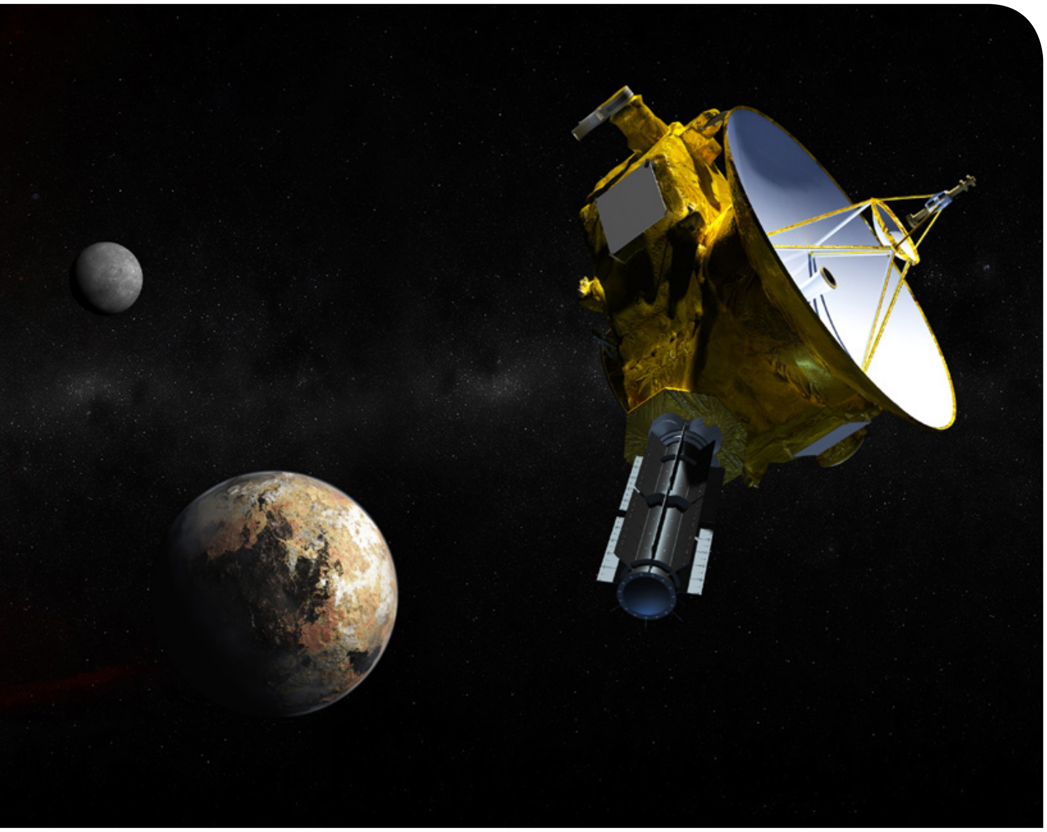
Using the Hubble Space Telescope, the researchers conducted a comprehensive analysis of the system and concluded that the two largest moons, Nix and Hydra, wobble chaotically as they orbit. Styx and Kerberos are expected to behave in the same manner, although further observations are needed to confirm this prediction. We can tell that the wobble is intensified by the fact that the four moons are not spherical in shape; they're elongated, much like a football.

Pluto was discovered in 1930 by astronomer Clyde Tombaugh at the Lowell Observatory in Flagstaff, AZ. Shortly after the New Horizons mission was launched in 2006—and after the discovery of another Kuiper Belt Object (Eris) —astronomers voted to demote Pluto from its planetary status. In honor of Tombaugh, a small New Horizons carries some of his ashes on board as he passed away before the mission could get off the ground.

Astronomers want to know how a system like Pluto and its moons could form. The prevailing theory: Pluto collided with another large body in the distant past, and much of the debris from this impact went into orbit around Pluto, eventually coalescing to form Charon. Scientists believe that a similar collision led to the creation of Earth's moon, so the study of Pluto and Charon could help scientists decipher the history of our own planet.



Artist's impression of the New Horizons spacecraft encountering a Kuiper Belt object.
Credit: JHUAPL/SwRI



Artist's concept of the New Horizons spacecraft as it approaches Pluto. The craft will study the global geology and geomorphology of Pluto and large moon Charon, map their surface compositions and temperatures, and examine Pluto's atmosphere in detail.
Credit: Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute (JHUAPL/SwRI)

Scientists want to figure out why Pluto and Charon look so different. From Earth, the Hubble Space Telescope and New Horizons, we have seen that Pluto has a reflective surface with distinct markings indicative of polar caps. Charon's surface is far less reflective, with indistinct markings. Pluto has an atmosphere, and Charon does not. Is the sharp contrast between these two bodies a result of evolution or is it due to how they formed? New Horizons will hopefully be able to solve this mystery.

Pluto's density, size and surface composition are strikingly similar to those of Neptune's largest satellite, Triton — a captured body from the Kuiper Belt. One great surprise of Voyager 2's exploration of the Neptune system was the discovery of ongoing cryovolcanic activity on Triton. Will Pluto or other KBOs display such activity?

Another fascinating aspect of

Pluto is its surprisingly complex atmosphere. Although Pluto's atmosphere is about 300-600 times less dense than Mars' — which is, in turn, about 150 times less dense than Earth's — it offers unique insights into the workings of related planetary atmospheres at Triton and Titan. Whereas the Earth's atmosphere contains only one gas (water vapor), Mars contains two (water vapor and carbon dioxide), and Pluto's atmosphere contains three: nitrogen, carbon monoxide and methane. Pluto's atmosphere has also puffed up over the years instead of dissipating. Scientists hope to determine why.

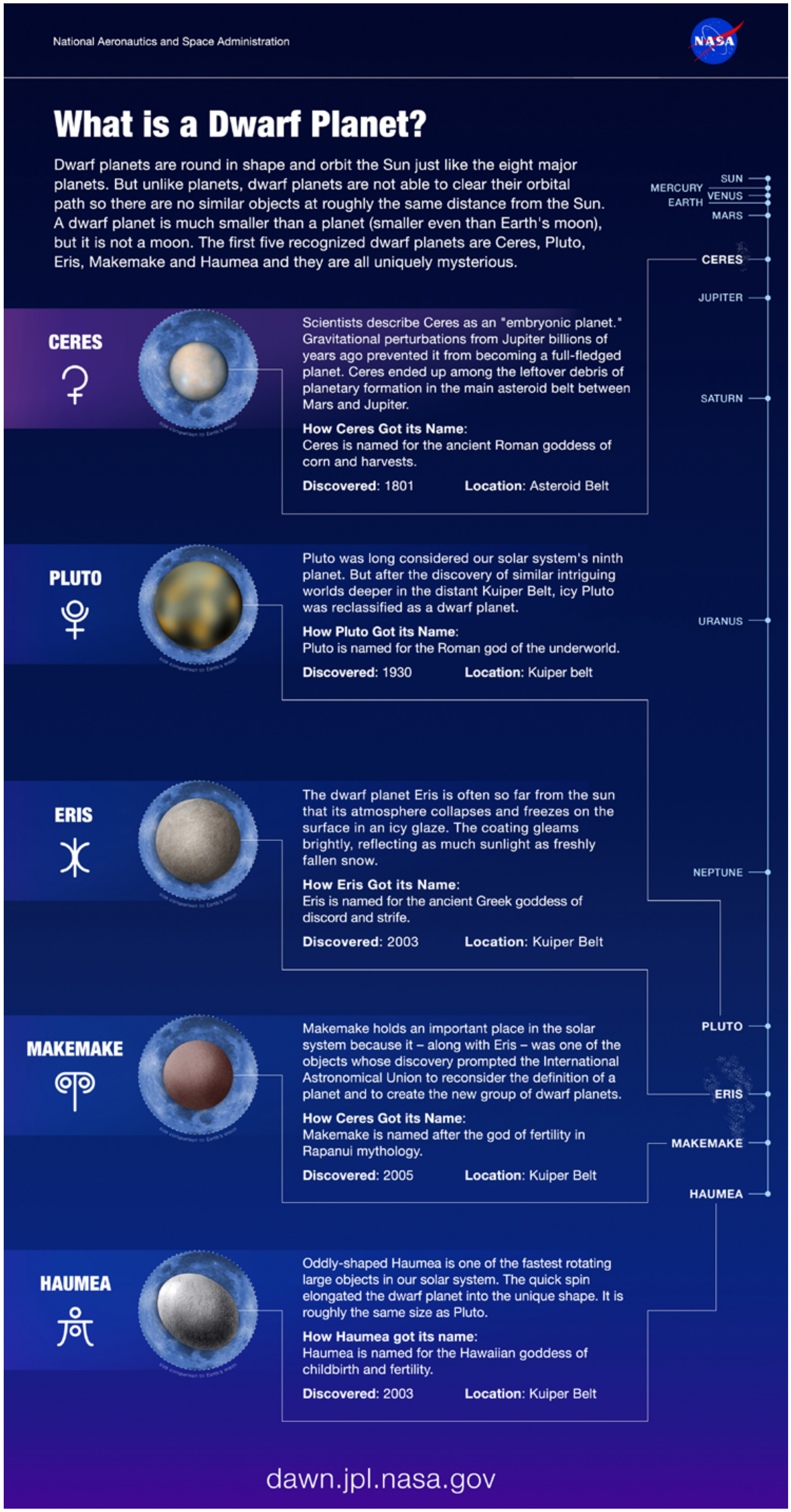
New Horizons is outfitted with a suite of nine different instruments including two cameras—Ralph and LORRI. Until recently, the only images of the dwarf planet were in black and white. With the release of the first color images, and now the first color map, we can see that Mars may not be the only red planet.

Scientists have known for decades that Pluto is reddish brown; however, now we can see it in detail and in living color. Although Mars and Pluto have similar hues, they are due to two very different reasons. Mars gets its red coloring from iron oxide (aka rust). Pluto's reddish coloration is likely attributed to hydrocarbons (tholins) formed when cosmic rays and ultraviolet light interact with atmospheric and surface methane.

As a result of chemical reactions, the tholins are formed and drop to ground, forming a reddish gunk that gives Pluto its color. Tholins are found in other parts of the Solar System as well, such as Saturn's largest moon Titan and Neptune's largest moon Triton—thought to be a twin of Pluto.

New Horizons is expected to give us unprecedented data on the whole Pluto system for many months following the flyby, including data about its surface, its moons and its environment, refining our knowledge of the dwarf planet and its system.

Pluto is not the last stop for New Horizons. In 2014, the Hubble Space Telescope identified three possible KBO's beyond Pluto for the probe to flyby. If NASA approves and there's funding, the spacecraft will visit one in 2019.



What is a Dwarf Planet? infographic uploaded to the JPL wwebsite by Jelly. http://www.jpl.nasa.gov/infographics/infographic.view.php?id=11268

Credit: NASA/CXC/JPL-Caltech/NOAO/DSS

Stellar sparklers that last

While fireworks only last a short time here on Earth, a bundle of cosmic sparklers in a nearby cluster of stars will be going off for a very long time. NGC 1333 is a star cluster populated with many young stars that are less than 2 million years old -- a blink of an eye in astronomical terms for stars like these expected to burn for billions of years.

This new composite image combines X-rays from NASA's Chandra X-ray Observatory (shown in pink) with infrared data from NASA's Spitzer Space Telescope (shown in red) as well as optical data from the Digitized Sky Survey and the National Optical Astronomical Observatories' Mayall 4-meter telescope on Kitt Peak (red, green, blue). The Chandra data reveal 95 young stars glowing in X-ray light, 41 of which had not been seen previously using Spitzer because they lacked infrared emission from a surrounding disk.

To make a detailed study of the X-ray properties of young stars, a team of astronomers, led by Elaine Winston from the University of Exeter, United Kingdom, analyzed the Chandra X-ray data of both NGC 1333, located about 780 light-years from Earth, and the Serpens cloud, a similar cluster of young stars about 1,100 light-years away. They then compared the two datasets with observations of the young stars in the Orion Nebula Cluster, perhaps the most well-studied young star cluster in the Milky Way galaxy.

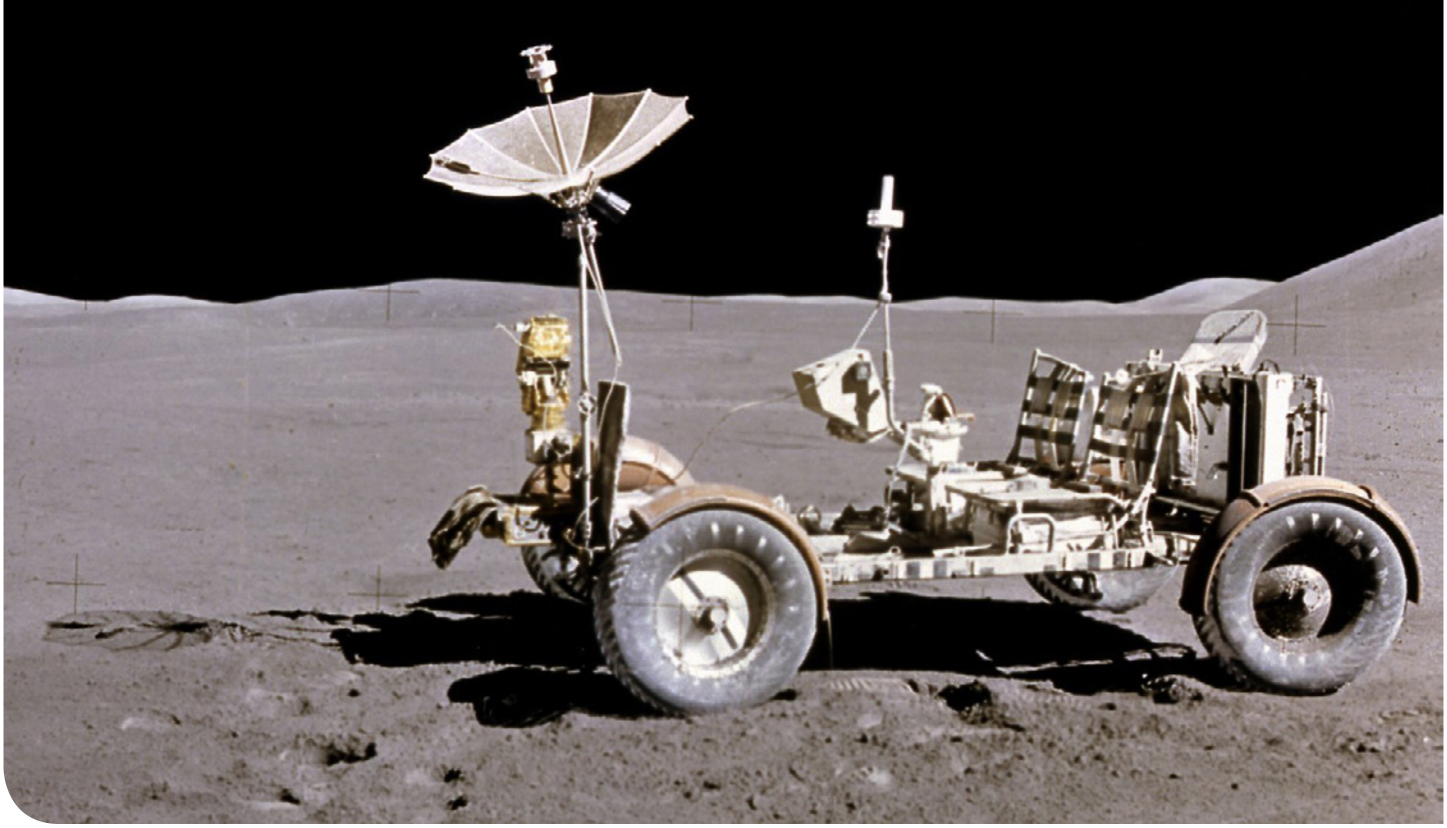
The researchers found that the X-ray brightness of the stars in NGC 1333 and the Serpens cloud depends on the total brightness of the stars across the electromagnetic spectrum, as found in previous studies of other clusters. They also found that the X-ray brightness mainly depends on the size of the star. In other words, the bigger the stellar sparkler, the brighter it will glow in X-rays.

These results were published in the July 2010 issue of the Astronomical Journal and are available online.

NASA's Marshall Space Flight Center in Huntsville, Alabama, manages the Chandra program for NASA's Science Mission Directorate in Washington. The Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, controls Chandra's science and flight operations.

NASA's Jet Propulsion Laboratory in Pasadena, California, manages the Spitzer Space Telescope mission for NASA's Science Mission Directorate, Washington. Science operations are conducted at the Spitzer Science Center at the California Institute of Technology in Pasadena. Science operations are conducted at the Spitzer Science Center at the California Institute of Technology in Pasadena. Spacecraft operations are based at Lockheed Martin Space Systems Company, Littleton, Colorado. Data are archived at the Infrared Science Archive housed at the Infrared Processing and Analysis Center at Caltech. Caltech manages JPL for NASA.

For more information about Spitzer, visit: http://spitzer.caltech.edu and http://www.nasa.gov/spitzer.



The Lunar Roving Vehicle (LRV) was taken during the Apollo 15 mission. Powered by battery, the lightweight electric car greatly increased the range of mobility and productivity on the scientific traverses for astronauts. It weighed 462 pounds (77 pounds on the Moon). Credit: NASA

The difference it made:

Building a car for the Moon

By David Clow

Neil Armstrong set the first distance record with an impromptu amble to Little West crater. Pete Conrad and Alan Bean exceeded that several times over by circling out and down into Surveyor Crater. Edgar Mitchell still holds the title for longest one, over a mile, made when he and Alan Shepard went looking for Cone Crater.

The Lunar Reconnaissance Orbiter photos tell the stories: for Apollo 11, 12 and 14, the dark trails scuffed in the dust show tentative explorations in this most dangerous place, where even a short hike was risky, and time was always precious. They were Moon *walks*, and triumphant as they were, they were frustratingly limited.

The astronauts on the first three lunar landings crossed a quarter-million miles of space to investigate, at most, a few hundred yards of the lunar surface. Something more was needed to turn Apollo into real exploration.

Out of the Cold War

The science fiction vision of driving on the Moon actually preceded the fact of driving on the Earth. It turned real as the space race accelerated. Cold War fear was an impetus as much as peaceful scientific curiosity.

Military contractors such as Grumman, Northrup and Boeing, already involved in lunar spacecraft design, created speculations on lunar surface vehicles of all configurations—one-man, two-man, long traverse, short-hop, rolling RV-sized habitations (the Mobile Laboratory, "MOLAB") that could carry multiple crew and operate autonomously for weeks at a time; even a rocket-belt that would boost an astronaut on twin hand-controlled jets.

Billions of dollars were at stake, both for Apollo and for the permanently-based militarized Moon that the Pentagon envisioned in its 1959 proposal for Project Horizon: "The lunar outpost is required to develop and protect potential United States interests on the Moon; to develop techniques in Moon-based surveillance of the earth and space, in communications relay, and in operations on the surface of the Moon; to serve as a base for exploration of the Moon, for further exploration into space and for military operations on the Moon if required; and to support scientific investigations on the Moon."

The ambition boggled minds and budgets: they set a deadline of 1966 to open the base, and planned expansion in 1967 requiring a launch schedule of over 200 Saturn I and II boosters, a new launch complex on the Equator; and a Vehicle Assembly Building at Cape Canaveral with six support bays for Apollo launch vehicles.)

This was the Cold War crystallized: money was no object and the Earth was not big enough for it. Not surprisingly, General Motors Defense Research Laboratories (GMDRL) a wing of one of the most powerful companies in history as the space race gained momentum, wanted in.

Mieczyslaw Bekker was head of the Mobility Research Laboratory at GMDRL. Born in Poland 1905 and graduated from Warsaw Technical University in 1929, Bekker had worked for the Polish Ministry of Military Affairs, doing pioneering research off-road traction for tracked vehicles.

The German invasion of Poland forced his group to flee to Romania and then, in 1939, to France, where in 1942 the government of Canada offered him a chance to move to Ottawa. After 13 years in the Canadian army, he retired and in 1956 moved to the United States.

Bekker's 1956 *Theory of land locomotion: the mechanics of vehicle mobility* was a forerunner of engineering in off-road vehicles that would help lead in the development of their ultimate expressions. In 1956, Bekker was hunting for talent. As a former refugee himself, he knew where to look.

Ferenc Pavlics

Ferenc Pavlics was newly-arrived in the United States. He and his wife had made a harrowing escape from Hungary after the uprising that had nearly thrown off Soviet control and then provoked a vicious response from Moscow.

Pavlics had been working as a design engineer at the Machine Industry Design Institute in Budapest and teaching at night at the Technical University of Budapest. He and his wife crossed the border into Austria past canine patrols and Soviet soldiers. Pavlics was carrying his own KGB file; had he been caught they would surely have been severely punished.

After months of waiting and uncertainty, the Pavlics committed themselves to go to America, and along with 4,000 of their countrymen, they boarded a re-commissioned World War II troop carrier.

Almost 40,000 refugees were received in Camp Kilmer, a reactivated military base in New Jersey. Bekker found a trove of talented engineers there, and within a week Ferenc Pavlics was on his way to a GM job in Detroit. In 1960 GM moved the Defense Research Laboratories to Santa Barbara, with lunar vehicles on the agenda, and wheeled tracks in the lunar regolith—possibly—just a few years away.

Limited time, many questions

It is worth reminding ourselves how little was actually known about the Moon at the time. The most effective exploratory tool in 1960 was the same one Galileo had used three centuries earlier: the telescope.

Pavlics and his colleagues were designing for a surface whose nature they did not know. Scientists such as Cornell's Dr. Thomas Gold speculated that it might not be a "surface" at all, just a thick, soft layer of dust that would engulf anything that touched it. To cope with that, some early ideas from GMDRL and its competitors featured fat balloon tires, huge spring wheels and even an idea for a version of an Archimedean screw that would burrow through a deep layer of dust.

Ferenc Pavlics in his Santa Barbara, California home. Credit: David Clow

The learning curve started with unmanned landers. GM collaborated with the nearby Jet Propulsion Laboratory in Pasadena, where planning for JPL's Surveyor lunar soft-lander was underway.

In 1963 Bekker and Pavlics offered a proposal for a tiny six-wheeled solar-powered vehicle that would ride down to the Moon aboard Surveyor and then slither down off it onto the surface. That never materialized, but it did offer both GM and JPL a starting point. (General Motors' wire-tire idea started there, later to blossom with the ones on the Apollo Rovers; and JPL's confrontation with the need for pitch and roll in a roving vehicle led them eventually to the rocker-bogie solution first used on the Mars Pathfinder Sojourner.

Month-by-month and mission-by-mission the nature of the surface was revealed, and it proved have the bearing strength required for the ambitious vehicle designs being created by NASA and its contractors.

GM's people were just a fraction of the hundreds of thousands of engineers, designers and fabricators at contractors all over the United States who were building unprecedented hardware to impossible standards on breakneck schedules, and not a bolt on any of it was independent of everything else.

The question was not whether the Moon could carry the loads, but whether the boosters, the schedule and the taxpayers could bear them.

NASA still clung to visionary ideas out of Chesley Bonestell of pressurized rolling habitations but the ruthless standards of weight, time and money repeatedly took the blueprints off the table. It all had to work together.

All the farsighted ideas for lunar vehicles were feasible, but in the unforgiving context of the space

Lunar Rover No.1, is stowed inside the Apollo 15 Lunar Module at the Manned Spacecraft Operations Building at Kennedy Space Center, Florida. When completely stowed, all four wheels of the LRV are folded against the chassis. Credit: NASA via Retro Space Images

race, none of them worked. They were too costly, too ambitious for the mission profiles, and above all just too heavy to carry. When reality was being measured in terms of grams and ever-tighter dollars, the lunar surface vehicle designers were still imagining in terms of tons, and eventually they had to concede the obvious. For Apollo, there would be no two-week surface expeditions, no separate Saturn cargo launches to place machines up there.

The need was bare-bones simple: aboard a single Saturn launch along with everything else needed for a mission, a vehicle that would be stripped to the minimum, used flawlessly but only once, and abandoned.

By 1967, when there were no realistic proposals on the table and the clock was ticking down to President Kennedy's deadline, NASA said it could not be done.

But the hope was just too good for General Motors to leave behind, and the need was obvious. The most scientifically promising places on the Moon were also the most hazardous to reach; and what was the point of risking a landing at a site like the Apennines or Taurus-Littrow if the safe radius of walking exploration was half a mile around the LM?

However, developing a spacecraft took five years by the most optimistic schedule, and the ones for the Command Module and the Lunar Module had proven unrealistic. "This is 1967, 1968," Pavlics remembered, "and it's really late in the program to create a new vehicle that could be ready.

"North American already has to redesign the Command Module after the fire. The LM is behind schedule too. So NASA's path is set. It was 1968 or so when they cancelled MOLAB and it looked like it was all done for vehicles. Then, independent research and development money provided by GM was used in our study—even if NASA did not want to pursue this, we still did.

"We did a study of how to create a vehicle to all the required specs and fit it either inside or attached to the outside of the existing LM. We went to NASA headquarters and talked with the brass and asked, can you identify what space might be available on the LM? We were also in contact with Grumman. They said, well, this small corner could be made available. Whatever was in there could be repositioned and the space freed up—we could use that much for whatever GM came up with. They we came home and started figuring it out."

The "small corner" was inside the descent stage to the right of the ladder as one faces the LM. It was "a triangular bay 60 inches high, 70 inches wide at the base, and 36 inches deep"…. just over thirty cubic feet, and the shape of it narrowed from the broad end to a point like a tall, wide slice of layer cake. "Figuring it out," as Pavlics put it, meant visualizing a way "to store a Jeep size vehicle carrying a payload of 1,200 pounds into a space not larger than the back of a station wagon." The solution Pavlics figured out changed the Apollo program.

"I came up with this idea of folding the vehicle," he said, "but nobody could really visualize it. That's why I built a little 1/6 scale model and with that, people could see it. Some of the pieces that needed machining we did in the shop at GM, but I made most of it and assembled it here at home. [For the wheels] I bought some stainless steel mesh off the shelf and cut it to the right size, rolled it into a cylinder and then knitted the ends into a torus shape.

"The 1/6 scale was perfect for the passenger, an Astronaut G.I. Joe with a silver Mercury-type space suit that I borrowed from my son. My wife and I made an Apollo backpack. She helped to sew the folding seats. The instrument panel and the steering joystick, the wire wheels with the titanium bumpers, the folding seats, the way the front and rear sections folded up and the wheels tucked in; it was all accurate, all to scale. And it was radio-controlled, so you could unfold it, sit G. I. Joe in the seat, and drive it on the floor.

"GM knew I was doing it," he continued, "but NASA was out of the loop. We were trying to sell the idea: look NASA, it's possible to do this! We went to NASA headquarters, to Houston, and to Huntsville, and gave presentations demonstrating the model. We made a scale model of the space in which it had to fold, and showed how it worked.

"In Huntsville, we pitched the engineering group. One of them, Len Bradford, led the way to von Braun's office and he opened von Braun's door. Instead of going in, I put the model Rover on the floor. von Braun was on the phone and the model drove in over his rug. He hung up and said, 'What the heck is this?' We gave him the presentation of how it worked, how it folded. The week after, he called in [NASA Project Manager] Sonny Morea, and Morea became the program manager to develop the [Rover].

"NASA issued another Request for Proposals. GM bid against Bendix for the job; it was pro forma really, because our folding and packaging design couldn't be duplicated. We got the contract and we and Sonny Morea had just 17 months to deliver the Rover."

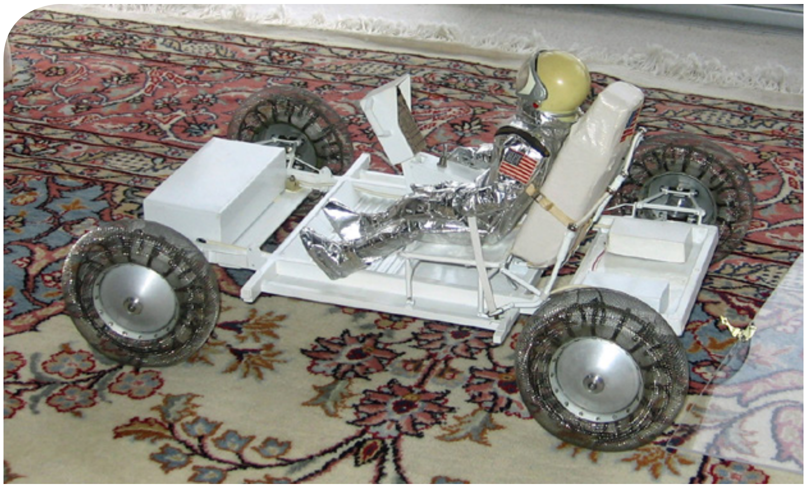
Close-up of the LRV tire exterior, showing the woven piano wire and the titanium treads. A Delco Electronics press photo from the GM Public Relations Department states, "The mesh is steel music wire, 0.033 inched in diameter, crimped at 3/16 inch intervals, cut into 800 32-inch strands, and then woven by hand and shaped to form a tire body. The mesh, containing some 64,000 intersections of wire, is mounted to a spun aluminum disc. The herringbone tread strips are made of titanium for abrasion resistance. Inside the tire, titanium bumper rings limit deflection of the mesh as the wheel bumps on the lunar terrain." Credit: David Clow

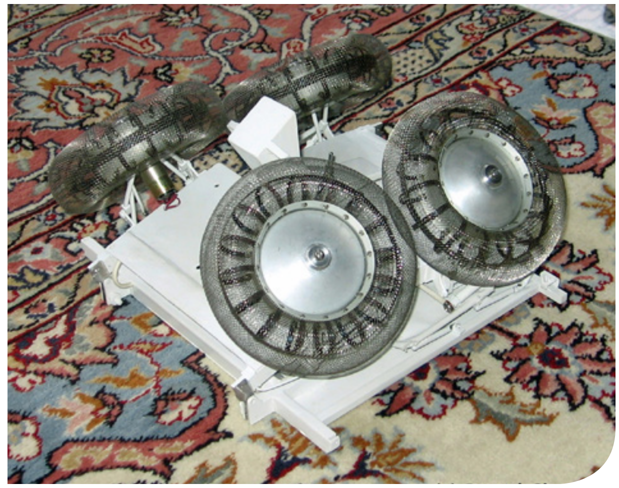
Specifications and pressure

It was to be a spacecraft every bit as much as were the CM, the LM and the EVA suits. Morea's office specified as absolute the requirement that "no single point failure shall abort the mission and no second failure endanger the crew," so regardless of the deceptive simplicity of it, and the casual sense of familiarity its design and the nicknames like "Moon buggy" invited, the LRV was subject to the same inviolable standards as all the rest of the Apollo hardware. The unprecedented challenges included creating a vehicle that had to:

- deploy safely in 1/6 G from the bay on the LM Descent Stage and be operable within 15 minutes or so;
- operate in a vacuum with temperatures between ±250 degrees Fahrenheit;
- permit ease of use by drivers wearing bulky protective suits;
- cross obstacles a foot high and over two feet deep;
- work without a transmission and gears, using instead four motors, one for each wheel, and operate if three of the four motors were out;
- permit the operators to venture miles from, and out of sight of, the Lunar Module while still being able to return to it in the minimal time, that is, not by retracing their path but by the most direct route;
- communicate via television and radio (voice and telemetry) with Houston in real time for the performance of both astronauts and the LRV, plus in support of the scientific objectives at each location visited;
- protect itself from temperature extremes and dust, and dissipate its own heat;
- weigh only about 450 pounds in 1G, about 75 in 1/6 G, and carry more than twice its weight;
- climb grades as steep as 25 degrees, and remain stationary when parked on a grade of 45 degrees;
- turn in a radius equal to its own length;
- provide real-time feedback on its condition to the operators and to Mission Control; isolate faults in its batteries and take corrective action; and
- deliver maximized freedom of movement for the greatest possible scientific exploration of every site.

It also had to do something no spacecraft to date had done: operate without ever having been tested under actual working conditions. Its first Apollo EVA would be its shakedown cruise, over two kilometers out in the Apennines past Rhysling and Elbow, then looping back along the gaping Rima Hadley on the way





Ferenc Pavlics' original 1/6 scale Lunar Roving Vehicle model, which he drove across the floor of Dr. Wernher von Braun's Huntsville office. The model LRV is folded (right photo) to demonstrate how the full-size Rover could fit into the available space in the Lunar Module descent stage. Credit: David Clow

back with the lives of Dave Scott and Jim Irwin riding on it. The accelerated timeline was:

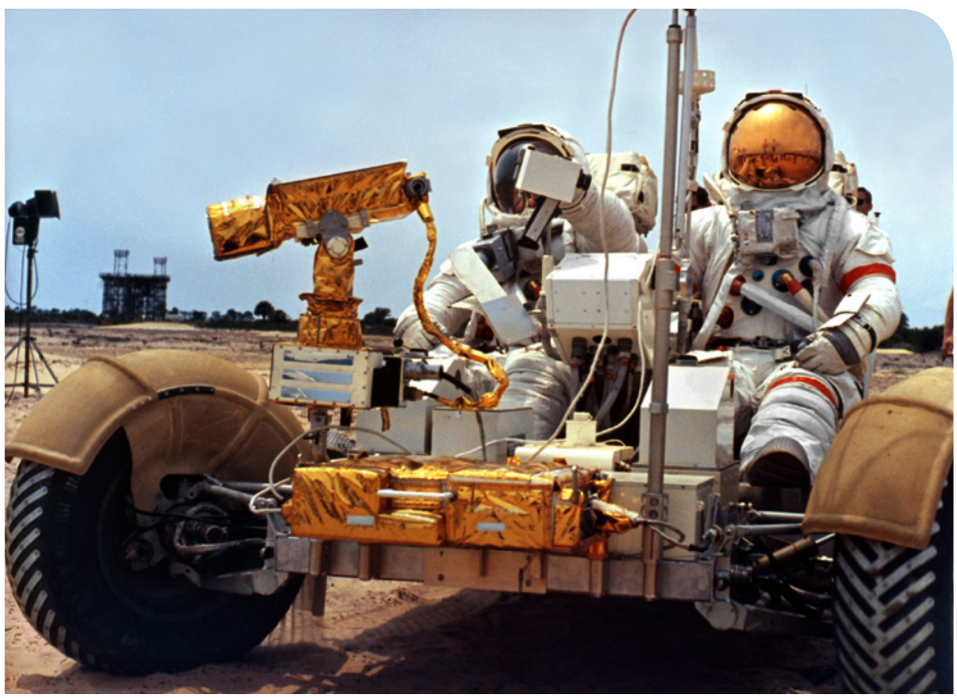
- May, 1968: GMDRL becomes AC-Electronics Defense Research Laboratories (AC-DRL).
- June, 1968: AC-E Defense Research Laboratory proposes packaging a disposable vehicle on the LM that can meet all the requirements and stay under weight constraints.
- May 23, 1969: NASA commits to the Lunar Roving Vehicle (LRV).
- June, 1969: Saviero Morea is put in charge of the Lunar Roving Vehicle Project Office at Marshall Space Flight Center in Huntsville.
- July 11, 1969: Morea's office issues the RFP to 29 companies to build the LRV. They schedule a preliminary design review in ten weeks, and a critical design review in 22 weeks with contract approval.
- July 11- October 28, 1969: Morea's office and team of engineers evaluate proposals from Grumman Aerospace, Chrysler Space Div., Bendix Corp, and the Boeing Co. It comes down to Bendix and Boeing with Boeing picked on October 28.
- October 28, 1969: MSFC announces Boeing as the winner and General Motors's AC-Electronics Defense Research Laboratories as the prime subcontractor. Boeing has ten weeks to finalize the details of eight systems on it.
- January 18-19, 1970: All-hands preliminary design review at Marshall with 120 NASA, Boeing and other personnel and John Young, Gerald Carr and Charles Duke.
- June 16-17, 1970: Final certified design review at Marshall. The design is considered complete and production of the vehicles could proceed. ,
- July 26, 1971: Apollo 15 lifts off.

Rush, rush, rush

"When we got the contract," Pavlics said, "we had less than 18 months to design, test and deliver the first Rover to NASA according to specifications for manned space flight. GM needed a partner for vacuum testing and conditions testing. We didn't have those capabilities.

"GM didn't have any background in space, after all. Boeing in Seattle did. We had partnered on MOLAB with Boeing and agreed on delineating duties.

"Boeing would handle the power system, navigation, communication and integration with the LM, and GM would do the vehicle itself including the chassis, wheels, suspension, steering, electric drive, controls and displays. We had some testing capability at GM but the qualification testing had to be done by Boeing.



David Scott, commander, at right, and James Irwin, lunar module pilot, at left. train with the Lunar Roving Vehicle (LRV). Credit: NASA via Retro Space Images

They had someone on site with us to ensure close communications. Both NASA and Boeing had a permanent presence here, in fact.

"That 18 months was rush rush rush," he continued, "a nonlinear schedule of simultaneous systems development and testing in parallel. Fortunately, we had plenty of knowledge to leverage and lots of the hardware had been developed, so we weren't starting from scratch. Also, we assigned parallel teams where each major subsystem had one engineer in charge—steering, traction and so on—and they were responsible for not just the design but carrying it all through testing and redesign and so on until delivery.

"In critical areas like electric drive, we had parallel and simultaneous development of alternatives, one with a DC drive and one with an AC drive, with the subcontractors. We knew we'd pick one, and we would commit to the best when the time came. That's how we cut development time. We did experience test failures, and weight was a serious constraint. Every morning, my first meeting was a weight analysis meeting, with the engineers contending over every gram.

"This was a highly compressed schedule," he said. "Nothing in Apollo had been started and stopped like this. It was day and night, weekends; our families hardly saw us. Nobody died, but some people got sick. But the great thing was, the people were so enthusiastic. You didn't have to prompt people, or ask "Can you stay an extra hour today?" Everyone volunteered and worked together, 400 people from Santa Barbara working on this in a very enthusiastic team effort.

"NASA was following it very closely. I don't think at the beginning they believed it. The top Apollo people seemed very dubious…Mueller, Low…Rocco Petrone seemed skeptical. This little outfit in Santa Barbara, no space experience; but the crew was testing the land version and training on how to be field geologists. […] We made the deadline. It was delivered two weeks before the launch."

The Lunar Rover is folded up and being moved into its stored position inside the Apollo 15 Lunar Module, where it will remain until its deployment on the Moon's surface. Credit: NASA via Retro Space Images

Wheels on the Moon

The Lunar Rover enabled the fulfillment of Apollo's most ambitious promises. The difference it made can be seen in the Lunar Reconnaissance Orbiter photos of the landing sites for the last three Apollo missions.

Where their predecessors has covered yards, the J-mission landing crews covered miles--a total of 58--collecting over a quarter-ton of samples from multiple locations in fast but comprehensive surveys of the Marsh of Decay, the Descartes Highlands and the Taurus-Littrow Valley.

More than that, it may have saved Apollo entirely. After the near-disaster on 13, said Dave Scott, "the program was in serious trouble. It was behind schedule, over budget, and not satisfying its basic requirements.

By June 1970, two months after the near-loss of the Apollo 13 crew, termination of the program was being seriously considered." Under pressure, with the budget cut, with the public losing interest and the scientific community demanding better results, NASA leaped ahead with voyages into more dangerous and interesting territory, with advanced equipment and the use of the LM as a base camp from which long traverses could be made, instead of as the sole determinant of the range of exploration.

With these began the true science of lunar exploration, and the process of learning how the Moon was formed.

"For our mission on Apollo 15, (as well as 16 and 17)," Scott continued, "the shift to a 'J' mission and the inclusion of the LRV meant that we could cover seven times the distance covered on 'H' missions. We would travel almost four times the distance from the LM, we would be able to carry many more tools, and we could collect and return twice the amount of surface rocks and soil.

"Further, because of the mobility of the LRV, we would be able to explore three different geological areas at our landing site, from a rille, to large craters, to the mountains; a true boon to the scientific exploration and comprehensive understanding of the Moon." The "J "missions, said historians Charles Murray and Catherine Cox, were "magical"—"through them, planetary science was transformed."

Please visit our website for the entire list of source material consulted during the writing of this article.

The author thanks Ferenc Pavlics and Dave Scott. This originally appeared in expanded form in Quest, The History of Spaceflight Quarterly, 18:1, 2011. Thanks to Scott Sacknoff, Publisher, and Dr. David Arnold.

The HONOR *of being an* ASTRONAUT

"Do you know what they did down on the Moon? What those guys' primary job was? They picked up rocks and dirt. Now, myself, in lunar orbit..."

– Al Worden, Apollo 15 CMP

USAF Colonel Alfred Worden served as Command Module Pilot for Apollo 15 – the fourth manned lunar landing mission. He also holds the record for the furthest deep-space Extravehicular Activity (EVA) (more commonly known as a spacewalk) any astronaut has ever done. He spent 38 minutes working in the vacuum of space, getting a perfect view of both his home planet and the Moon at the same time. Worden has spent, in total, 295 hours and 11 minutes in space. On top of his many accomplishments, he has authored three books: "Hello Earth! Greetings from Endeavour", "I Want to Know About a Flight to the Moon", and his autobiography, "Falling to Earth".

I, along with our photographer, Julian Leek, planned to meet with Worden for brunch on a Sunday afternoon for this interview. I arrived a little early on that day and when I walked into the restaurant, there was a framed photo of the view of Earth from the moon on the wall, signed by him. The host sat me at "his table" and let me know it was the one he likes the most. I had barely set my stuff down when I saw him walk in. Everyone working in the restaurant seemed to know him - I could tell that he was a regular. He greeted the staff with a huge smile and knew most of their names. When the waitress came to take our order, Worden suggested his usual choice. We had a delicious meal consisting of steak tidbits with eggs Benedict and great conversation before we got down to business.

When Worden tells a story, he makes you feel like you experienced it with him. He is genuine and what struck me about him was how open he was in giving his opinion on anything and everything I asked about. No question was too personal, nothing was off limits - he had a lot to say and was wildly fun with his answers. His opinions about his crewmates and people in his life were given in a lighthearted manner, and though he was very serious about his political, scientific and professional questions, he rarely told an entire story without inserting some clever, witty joke. By the end of the interview, the muscles in my face hurt from laughing so much and so hard.

I thought he would reveal a lot of poetic epiphanies he had as he traveled to the Moon and back, however, I realized that, ultimately, he was a man serving his country who simply did the job he was sent to do. I came out of this interview with an entirely new understanding of what being an astronaut is all about. Honor.

I present to you, the inner workings of the mind of Colonel Al Worden.

Interview by Sherry Valare

Al Worden with a model of the Command Module and Lunar Lander in 2014. Credit: Julian Leek

Al Worden enjoys a good Hawaiian print shirt almost as much as he loves a good laugh. Humor is a charming staple of his personality. Credit: Julian Leek

RocketSTEM: Where in your set of life experiences does going to the Moon rank?

Al WORDEN: "I can't give you an honest answer about where the Moon ranks in the high points of my life. What you have to understand is that going to the Moon is learning a skill. Its not a mental activity, as such. I think there are other things more important in my life than going to the Moon. That was certainly the high point in terms of how I lived and what I did and where I was, but I think there are other things that are higher - like writing a book. To me, writing a book – it requires intellectual power to write a book. It requires you to think, so I think writing a book requires more of a person than going to the Moon. So, the Moon was important, I loved it. In terms of what the media thinks about it, yes, it was the high point of my life, but it was not actually the highest point of my life.

"My high point was back in the 80's running for United States Congress. I thought that was a very important thing to do. I put everything into it and lost, but that is okay. The next is writing books, and I guess the lunar trip was in there somewhere too."

RS: Did you have any great epiphanies being in space? Is there anything that we cannot understand because we haven't been in space?

WORDEN: "I don't think people get Earth. I don't think people understand what Earth is. I don't think people understand that the Earth has a finite lifetime, I don't think people understand that the sun is going to burn out one day and we're not going to be able to live here anymore. I don't think people understand that it's important for us to organize our different societies and our different religions and our different political organizations to live peacefully here on Earth because if we don't we are going to destroy Earth before the sun is going to burn out. The way things are going right now, I think the Earth's lifetime is a lot shorter than what we would see if it ran all the way till the sun finally burns up all its energy.

"So...where was I? I got all tangled up in my own rhetoric! (Laughter)"

RS: What is something that only you could know because you went to space, that no one on the planet that hasn't gone to space could possibly know?

WORDEN: "Just about everything! (Laughter) People do not understand space or anything beyond what they can see, which from where we are right now, is a very short horizon. When you fly in an airplane you see a little horizon. When you fly in space, you see a big horizon. You see the Earth the way it is. I think that we are very uninformed about who we are, how we got here, where we are going and how much lifetime we have here on Earth. But you get a sense of that when you go to space."

RS: Do you think that we overestimate our importance in the universe?

WORDEN: "Absolutely! We, in general, think that we are the only ones in the universe that are like us. How wrong can you be! People do not have open minds about it. It is inevitable, absolutely inevitable, that there are other people out there that are not only LIKE us, but have a million years advanced on us, and they can come and go as they please. That is what we will be able to do in a million years, so we are behind them. I don't believe in UFO's because I've never seen one, felt one, or got a piece of metal off of one, a UFO is evidence and until that evidence is solid, I have a problem with that. BUT. If you look at the philosophical side of the equation, and you ask the question, "Do you think there is life out there?", the answer is absolutely, 100%, YES."

RS: How did you end up becoming an astronaut?

WORDEN: "I was born in Jackson, Michigan. My parents were just regular people, we had 6 kids in the family, and we lived on a farm. In fact, I ran the farm from the time I was 12. Something interesting- back in those days, if you were a kid living on a farm, you could get a driver's license when you turned 14. So the day I turned 14, my dad took me down to the driver's license bureau and I got my driver's license. I learned to drive on a tractor! I bought my first car at 15. I paid $30 for it and I had a whole succession of cars after that which I rebuilt and repaired.

"One of the things that was important to me was that since I was totally responsible for the farm, the cows, pigs, chickens, grow the corn, cutting the hay, until I was 18, when I went off to college I decided to put that behind me and that I was never going back to it. There was no way I was going to live the rest of my life on a farm. That kind of got me started down the path that led to NASA.

Worden suits up in preparation for a pressure chamber test on April 5, 1971 as part of his training for the Apollo 15 mission. Credit: NASA via Retro Space Images

"When I graduated from West Point in 1955, I elected to go in the Air Force - flying was a very exciting thing - even though I had no experience at all. When I went into flight training, I found that I had kind of a knack for it. When I graduated from pilot training, I went into Air Defense Command. When I was in that squadron in Washington, I got involved with the maintenance in the hangar and eventually took it over for the squadron commander. Air Defense Command wanted me to come up and walk around to all the squadrons in the country and teach them how to do that (maintenance in the hangar), too. I decided that if I'm going to do staff work like that, my best bet was to try to get back to college. If I was going to sit at a desk, I was going to do it for something that was good for me.

"So I got orders to go back to the University of Michigan. I spent two and half years there getting three master's degrees, and when I graduated from there, I applied for and got selected for test pilot school. I went to England to Empire Test Pilot School and graduated from there in 1964. The U.S. Test Pilot School was visiting just before I graduated, and they told me they needed me back at Edward's Air Force Base, so they got my orders changed to go there.

"I had been at Edward's for a year when I saw that NASA had a request for applicants.

"At that point, I had all the squares filled. I had everything they needed, which was a little bit unusual back in those days. So I applied and got into the program. You had to have a certain amount of flying, you had to be academically qualified, you had to have very, very good efficiency reports leading up to that point. You had to be under 6' tall, under 35 years of age, pass a physical, all those things - and I could do all of them.

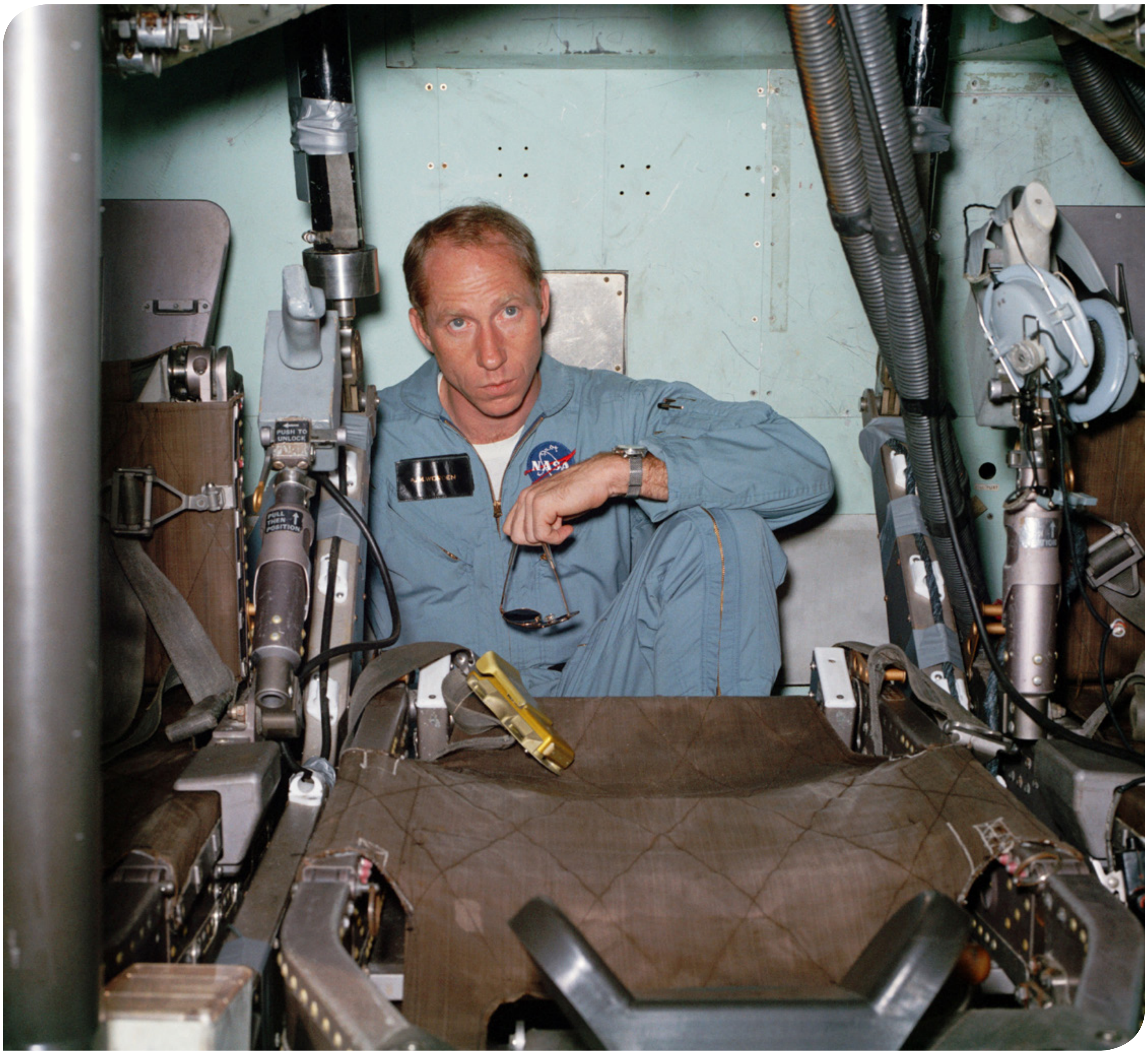
"I was lucky and got in, but I did not start out thinking that I wanted to be an astronaut. That was never in my mind. I just wanted to be the best pilot I could be. I tell kids all over the world when I talk to them, you pick whatever it is you want to do, but be the best there is at it when you do pick that, and you will find that at the end of the road, doors will open for you that you never even thought of.

"So, that's what happened to me."

RS: Speaking from your experience, what skill set would be most beneficial to a student today to get them ready for the astronaut corps?

WORDEN: "I don't think there is any one thing that a student has to focus on. I think whatever they do, it has to be in the sciences, in the STEM courses somewhere. But, I think that when they are in those courses, that have got to be outstanding. That's the key to it. They have got to put everything they have into it, and be at the top of their class and be the best there ever was. They also need to be in good physical shape.

"But, I would not tell any student that the astronaut program should be their end goal. Whatever specialty they are in, they have to be the best they can at that and it might happen that NASA needs that specialty at some point. I think it's a tragic mistake for them to go into it thinking they are going to study to be an astronaut, because if they don't make it, then they are going to be disappointed. I think they have to be the best they can at whatever they are. You cannot organize your entire life to have one outcome, it just doesn't work that way."



Worden sits alone inside the Command Module mockup during training before the Apollo 15 mission. Credit: NASA via Retro Space Images

RS: What kind of research and missions would you like to see happen in the future?

WORDEN: "I think we need to keep going outward. I don't care whether we go to an asteroid, I don't care whether we go to Mars. I think going to the Moon is probably a losing proposition at this point - we'll let the Chinese do that - they're going to do it. I think what we have to do is develop propulsion systems that get us way out there, not just in the solar system, but somewhere else. I absolutely believe we will develop the means of going faster than the speed of light. It might take us a thousand years, but you know, we had the same problem with the speed of sound and we proved that was nothing. We are going to develop machines and propulsion systems that are going to get us out there. I think propulsion is the secret to everything. And when we get a propulsion system that will get us where we need to go without expending a lot of resources, then we can truly begin to explore our neighbors outside the solar system. That's where we're going to find, probably, people like us."

RS: What legacy do you want people today and future generations to acknowledge?

WORDEN: "Legacy? If I had a 'theme song' that would make people understand what I would request, it would be 'independence'. Independent thought, independent work. Do not rely on somebody else, particularly the government, to do anything for you. This is a nation of independent people, this nation was born by people getting away from something and doing their own thing once they got here. We have lost that today. We need people who are independent in their thinking and their research, that are going to barge forward and do what's right to get this country out ahead. So I guess my thing would be independence and thriving."

RS: In the future do you think space will be accessible to the average person the way flying is now?

WORDEN: "No, not for a long time. Many of the similarities with aviation are out there. There was a time when going somewhere on an airplane for an average person wasn't going to happen. And there was some thinking that you would never fly from one city to another. Today, the only issue is, "Does the airline fly on time or not?". Space could get that way some day, but I'm just not sure that the cost and risk is going to be the same. The shuttle was supposed to be routine, but it wasn't, every flight was kind of different. We lost more shuttles than we lost Apollos. It was a very dangerous machine, it was not safe. We are now finding that SpaceshipTwo is not a safe spaceship. Even when it starts flying passengers, they're only going to go straight up and straight down. To me, that's not space. They can pay their $200,000 dollars and say they've been to space, but that's just a very, very momentary thing. That whole flight's only going to take 15 minutes. The difference between going straight up and down compared to going into orbit is about five times the speed. You have to go five times faster to go into orbit, and the only way to go to "space" is to at least go into orbit. So, in my opinion, SpaceshipTwo and all these others flying people up and down, aren't going into space. You'd have to be someone who can pay $20 million dollars to go, then you'd be going to space."

Worden was listed in the Guinness Book of World Records as the "Most isolated human being" during his time alone in Endeavour at the Moon. Credit: Julian Leek

RS: What direction do you hope NASA will head towards in terms of human spaceflight?

WORDEN: "Well, I think it's time for NASA to get off its butt! I think it's time for someone at NASA to have the courage, and the perseverance to make sure that we step out. It may not happen for a few years, but we are going to get there sooner or later, it's just that pressure to win. Going to Mars is important because it is going to force us to develop propulsion systems and life support systems that will manage a year and a half flight. The moon's only two weeks, you can do almost anything, it's easy to get to the moon. In fact, going to the moon is easier than going into Earth's orbit if you really want to know! It is a straight line flight! Going into Earth orbit, you're going around and around and around. I think the next step is Mars, then we'll probably be looking at some moon of Jupiter – Io or Europa – and each of these is an incremental step outward. Eventually we will develop the propulsion capability that will take us beyond that. You know the ancient Chinese proverb, 'A trip of a thousand miles starts with one step'? We've made the one step. Now we need to make the second one."

RS: Do you think there is life on Europa?

WORDEN: "I have no idea, and I don't really care. Who cares if there is life in the solar system? We are not going to find the kind of life in the solar system that we're looking for anyway. I don't care what it is, it could be biological life, plants growing there, but no, we have to go a lot further out to really find something that's compatible with the way we are."

RS: If you had an opportunity to fly into space again, what crew, mission and vehicle would you prefer?

WORDEN: "I would want a different spacecraft, I would love to go to Mars. It's a year and half trip. I would take guys like Paul Weitz and Jim Irwin (if he was still alive). I'd pick a crew like that - all of us old guys. I think the Mars trip is the trip for old guys. We have better far vision, but most importantly, we can sit still for days at a time! We've got patience. If they provided me with a television set I'd just sit there and watch it! I don't get the heebie-jeebies to move around and do things like a young guy would. So, we'd be much more adaptable for going to Mars than a young guy!"

RS: What if it was a one way trip?

WORDEN: "Who cares! I'm 82 years old! Who cares! I'm going to go sometime anyway. Might as well go doing something useful!"

RS: What is your favorite ... word?

WORDEN: "Honor."

RS: Color?

WORDEN: "Blue."

RS: Book?

WORDEN: "My own."

RS: Movie?

WORDEN: "2001: A Space Odyssey. It really sparked my curiosity. It really makes you think about what we are and it was very inspirational to me - a real eye opener. They had a lot of things right!"

RS: Animal?

WORDEN: "Dog."

RS: Song?

WORDEN: "Anything that The Beatles wrote. I was there in '64 when they were just hitting it big!"

RS: What did you think of the movie Gravity?

WORDEN: "I thought it was crappy. The special effects were amazing but the technical side of the movie was absolutely horrible. They got NOTHING right! You do not maneuver around in orbit from one space station to another using a fire extinguisher! That just cannot happen! And the meteor shower - those clip the edge of the atmosphere and keep going, they do not enter Earth orbit! They had everything wrong! And I did not like the role Sandra Bullock played! All she did was cry and scream the whole damned movie. The special effects were just fabulous, though!"

RS: What was your spacewalk like?

WORDEN: "I was 50,000 miles this side of the Moon and 200,000 miles from Earth. We went to the moon, stayed in orbit, came back and did it on the way. The cool thing about it was, I could see both Earth and the Moon at the same time."

Still frame from a video of Worden during his EVA to retrieve film from cameras in the SIM bay of the Command Module. Credit: NASA via Retro Space Images

RS: You orbited the Moon by yourself - what were you thinking about while you were alone in the spacecraft?

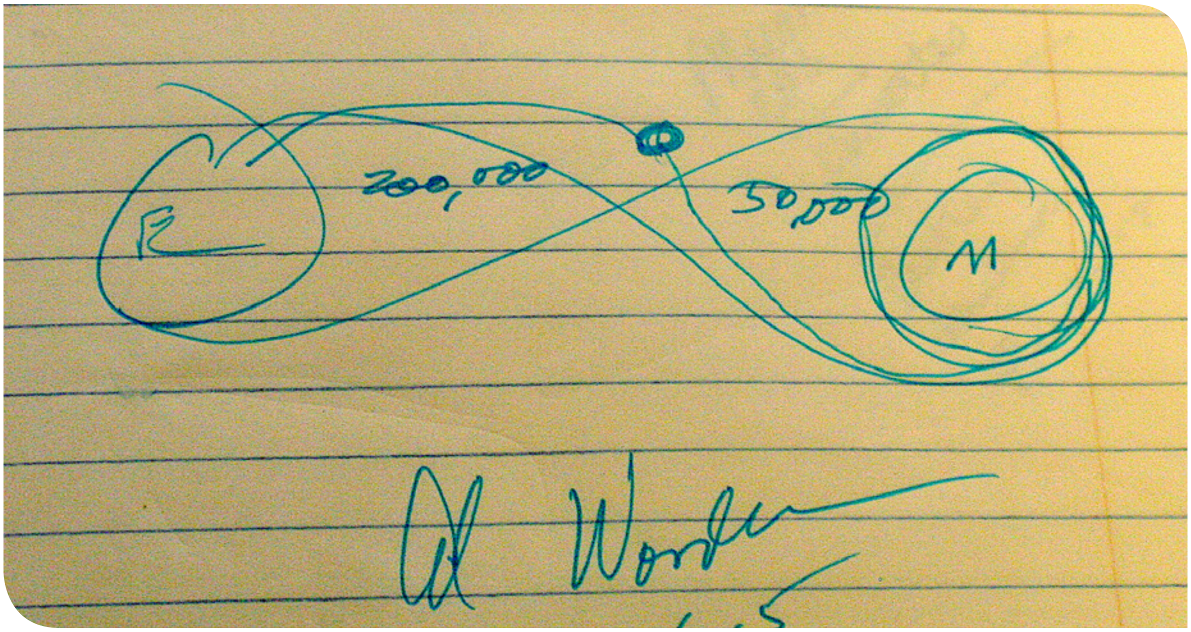
WORDEN: "Orbiting the Moon by myself was absolutely the best time of the flight. I got rid of two guys after being with them for about three and a half days; they were getting on my nerves (laughter). I was trained to fly an airplane by myself and I've always been a loner in an airplane. So, I was very happy being by myself. I got to the back side of the Moon, away from Earth, I didn't have to talk to Houston, I was in my glory! "

RS: So, did you draw the short straw or the long straw when it came to staying in the module or going down to the Moon's surface?

WORDEN: "Oh, I definitely got the long straw!

"What people remember as important is all due to the media. They have romanticized the guys that walked on the Moon. Do you know what they did down on the Moon? What those guys' primary job was? They picked up rocks and dirt. Now myself, in lunar orbit, I did probably a thousand times more science than they did, because I had all these remote sensors and big cameras and all kinds of things I was running the whole six days I was there. Dave and Jim picked up 170 pounds of rocks, huh? Big deal! (laughter)

"But I have to tell you that people focused on lunar walkers as some mystical thing. Jim Irwin even tried to put together an organization likening it to the last supper, where there were twelve astronauts that walked on the Moon. And he didn't include the Command Module Pilots. But what's curious about that is, 12 guys walked on the Moon, but only six guys went around it. The media



Al Worden drew this quick sketch during the interview of where he was when he made his spacewalk on the return trajectory to Earth.

Credit: Sherry Valare

made it such a big thing to have walked on the Moon. And it was a big thing, I don't want to take that away from them.

"As Command Module Pilot, I had thousands of things to do. Taking pictures, doing visual observations, photographing the surface of the Moon, I had a mapping camera that I used to map about a quarter of the Moon. There were lots and lots of thing to do while in lunar orbit. But the media made it so much more important to have walked on the Moon. I don't mind it. I am very happy about where I was, because when I flew, it put me in line to be a commander. That is the big difference.

"Also, those guys had all kinds of cameras down on the surface, and they took 7000 pictures of each other. I didn't take ANY pictures of myself."

RS: You didn't get a Moon selfie?

WORDEN: "I didn't take any selfies, no. When I trained for the flight and was on the flight, all I thought about was taking pictures, but of OTHER things."

RS: How did you come to terms with the possibility of not coming back?

WORDEN: "We had what I would consider to be a far Eastern thought process on that. There are some things more important in life, than your individual life - one of them is your honor. We were representing the greatest country in the world, and if we didn't come back, so be it. We were doing our thing. On the flip side of that, you do know that if you die in space, you're going to be known forever. Does that do me any good? No. But it's something to think about! And there were no suicide pills, again, that's from the media coverage."

RS: How did your family feel about you going to space and the Moon?

WORDEN: "The people in my family were basically pioneers. My mother grew up in a log cabin in northern Michigan. She was very stoic about things. My dad was a little more emotional. I think the only really emotional time they had was during launch because that thing was so noisy that if you're not a little emotional about it, there's something wrong with you. But once the thing was gone and I was in flight, they sat at my apartment the whole time I was gone, watched the TV, got updates, and I think they were fine with all of that. I think that as long as everything on a flight goes well, and all your updates are good, they're doing a lot of partying. I think they did a lot of that."

RS: What was the first thing you did when you got back on Earth?

WORDEN: "First thing was a physical, then we had lunch with the Captain on the USS Okinawa, then I went back to Houston, got home, and there was a party going on. THAT's when I had a vodka! Then another! Spent half the night partying, woke up the next morning, went back to the center and started debriefing. Debrief twelve hours a day, go home, party, debrief twelve hours a day, go home and party. By the end of that two weeks I was in much worse shape than I was when I was on the flight!! THAT almost killed me! Tough times! (Laughter)"

RS: What is on your bucket list?

WORDEN: "I have to tell you, I have too many things on my bucket list. A trip to South Africa, to China, building my own airplane, would all be on my bucket list."

RS: What was the most spectacular moment for you in space?

WORDEN: "Seeing the Moon up close for the first time. Getting into lunar orbit."

RS: And last, but not least, what did you think when you first saw the Moon?

WORDEN: "Pretty awesome!"

Premier of the J-series mission changed the game for Apollo 15

By Ben Evans

Four hundred miles (640 km) to the north of the Moon's equator lies a place called Hadley: a small patch of Mare Imbrium at the base of the Apennine Mountains, some of which rise to 4,000 feet (1,200 meters), and a 25-mile (40 km) meandering gorge, known as Hadley Rille.

In July 1971, Apollo 15 astronauts Dave Scott and Jim Irwin expertly negotiated these forbidding landmarks in the lunar module Falcon and set down in one of the most visually spectacular regions ever visited by mankind. They brought back a scientific yield which revealed more about the Moon's origin and evolution than ever before.

Forty-four years ago, this month in July-August 1971, Apollo 15 conducted one of the most brilliant missions ever undertaken in the annals of space science.

It is therefore ironic that this triumph actually arose from the ashes of defeat. Original plans called for four H-series lunar landing missions—Apollo 12 through 15—which would each spend 33 hours on the Moon and feature two EVAs. The final missions, belonging to the J-series, would perform longer missions, spend 70 hours on the surface, make three EVAs and utilize a battery-powered rover. In September 1970, everything changed when NASA canceled one H-series mission and one J-series mission; as a result, the schedule shifted to maximise the scientific harvest from the remaining flights. Apollo 15 was upgraded to the ambitious J-series and it was this decision which altered its scope and its place in history.

The countdown on 26 July 1971 was near-perfect. In fact, Launch Director Walter Kapryan described it as "the most nominal countdown that we have ever had". The astronauts—Scott, Irwin and command module pilot Al Worden—were awakened early that morning, breakfasted on steak and eggs, caught a brief nap as they were being suited-up and were helped into their couches aboard the Apollo 15 command module, Endeavour, at around 7:00 a.m. EDT.

The clang of the hatch shutting them in startled Irwin. "I think that is when the reality of the situation hit me," he later wrote in his memoir, *To Rule the Night*. "I realized I was cut off from the world. This was the moment I had been waiting for. It wouldn't be long now." From his couch on the right-hand side of the spacecraft, Irwin had little to do and had some brief respite to reflect on his life, consider the enormity of the mission ahead of him and, more than anything, give himself over to an air of anticipation and expectancy as he waited for the Saturn V to boost them toward the Moon.

Fifteen minutes before launch, they had felt and heard the unearthly clanking noise of the access arm moving away from the spacecraft, then beheld the stunning blaze of sunlight through the command module's only uncovered porthole. As the


Apollo 15 astronaut Dave Scott and the Lunar Rover with a view up Hadley Rille in the background. Credit: NASA via Retro Space Images

countdown entered its final seconds, the glare of the Sun was so intense that Scott had to shield his eyes, just to read the instrument panel in front of him. Precisely on time, at 9:34 a.m. EDT, the five F-1 engines of the Saturn V's first stage came to life with a muffled roar. "You just hang there," Irwin wrote. "Then you sense a little motion, a little vibration and you start to move. Once you realise you are moving, there is a complete release of tensions. Slowly, slowly, then faster and faster; you feel all that power underneath you."

Four days later, after crossing the vast, 240,000-mile (370,000 km) cislunar gulf, Apollo 15 slipped into orbit around the Moon. Scott and Irwin, aboard the lunar module Falcon, undocked from Worden, in the command module Endeavour, and began their descent towards the surface.

Moving in a sweeping arc towards the Apennines, at an altitude of 4 miles (6.4 km), Scott began to discern the long, meandering channel of Hadley Rille. The terrain was less sharply defined than he had anticipated on the basis of simulations, yet he was able to find four familiar craters: Matthew, Mark, Luke and Index—the latter of which they had used in landmark sightings from orbit. (The name "Index" was deliberately chosen instead of "John" in order to stave off complaints from the notorious atheist Madalyn Murray O'Hair, whose criticism of overtly religious symbolic gestures on missions had scalded NASA during the December 1968 mission of Apollo 8.)

Dropping through a gap in the lunar mountains, Scott suddenly had the surreal feeling that he was "floating" with strange slowness towards his landing site. "No amount of simulation training," he wrote in his memoir, *Two Sides of the Moon*, "had been able to replicate the view we saw out of our windows as we passed by the steep slopes of the majestic lunar Apennine Mountains."

In the simulator, they "flew" a television camera towards a small, relatively flat patch of plaster-of-Paris; now, doing it for real, they drifted between the astonishing 16,400-foot (5,000-meter) peaks of the mountains to both their left and right as they threaded their way towards Hadley. "It made us feel," he added, "almost as if we should pull our feet up to prevent scraping them along the top of the range."

As they continued to descend, Falcon's computer transitioned to the so-called "Program 66", enabling Scott to fly manually.

"Dave didn't want me looking at the surface at all," Irwin wrote. "He wanted me to concentrate on the information on the computer and other instruments. He wanted to be certain that he had instant information relayed to him. He was going to pick out the landmarks. But Dave couldn't identify the landmarks; the features on the real surface didn't look like the ones we had trained with."

Scott could see Hadley Rille, though, and used that long gouge as his marker, but was worried that

"No amount of simulation training had been able to replicate the view we saw out of our windows as we passed by the steep slopes of the majestic lunar Apennine Mountains."


Credit: NASA

they might still land "long", and far to the south of their intended spot. This fear was confirmed by Capcom Ed Mitchell; they were, indeed, 0.5 miles (0.8 km) or more south of track. Scott knew that, even with the rover, this might impair the effectiveness of their explorations.

During those final moments, he clicked his hand controller 18 times, forward and to the side, adjusting their trajectory to bring Falcon back onto its prescribed path.

Those seconds were so unreal—the clarity of the scene, the weird behavior of the lunar dust, the strange, almost-unpowered sense of drifting like a snowflake through the majesty of the lunar mountains—that Irwin mentally convinced himself that he was still in the simulator back in Houston. If he had admitted to himself that this was for real, he felt that he would have been just too excited to do his job properly. Yet if this was a simulation, it was one of the smoothest that he had ever flown. They were very close to the surface now and lunar dust obscured the landing site entirely, like a thick fog.

It was only Irwin's call that the blue Contact Light had illuminated which finally convinced them that they had touched down. The time was 6:16 p.m. EDT on 30 July 1971 and, with a firm thud, the seventh and eighth men from Earth reached the surface of the Moon. "Okay, Houston," radioed Scott, "the Falcon is on the Plain at Hadley!" His reference to the landing site as a "plain" paid due tribute to Scott's alma mater, the Military Academy at West Point, whose parade ground was also nicknamed "The Plain".

What did cause concern was that Falcon had come down on uneven ground and one of its rear footpads had planted itself inside a small crater. (Mission Control would later call their lander "The Leaning Tower of Pisa", an epithet which Scott did not appreciate!)

Irwin remembered the landing as the hardest he had ever been involved in; "a tremendous impact with a pitching and rolling motion. Everything rocked around and I thought all the gear was going to fall off. I was sure something was broken and we might have to go into one of those abort situations. If you pass 45 degrees and are still moving, you have to abort. We just froze in position as we waited for the ground to look at our systems. They had to tell us whether we had a STAY condition".

With some relief, 77 seconds after touchdown, Mission Control radioed their approval for Scott and Irwin to STAY.

"The excitement was overwhelming," Irwin wrote, "but now I could let myself believe it." They had set down in a beautiful valley, with the mountains of the Apennines on three sides of them and Hadley Rille about a mile (1.6 km) to the west. In his mind, it conjured up memories of the mountains of Colorado, high above the tree line; yet there was something else about it, too.

"The excitement was overwhelming, but now I could let myself believe it."

Irwin was certainly one of the more religious men in the astronaut corps and he would later make little secret of the fact that he acutely sensed the presence of a supreme being on the Moon. This sensation reached its sharpest whenever he looked up at the colorful Earth in the black sky. "That beautiful, warm living object looked so fragile, so delicate, that if you touched it with a finger it would crumble and fall apart," he wrote. "Seeing this has to change a man, has to make a man appreciate the creation of God and the love of God." This profound experience would remain with Irwin and guide his steps for the rest of his life.

One of the skills that Scott learned during his geology training was the need to gain a visual perspective of the site that he was about to explore. With this in mind, he requested mission planners to schedule a "stand-up EVA", a couple of hours after touchdown, in which he would stand on the ascent engine cover, poke his helmeted head through Falcon's top hatch and photograph his surroundings.

View from lunar orbit looking towards the Moon's South pole. Credit: NASA via Retro Space Images

At first, Director of Flight Crew Operations Deke Slayton opposed the idea, on the grounds that it would waste valuable oxygen, but Scott fiercely argued his case and eventually won approval.

To conduct this half-hour "SEVA", Scott pulled a balaclava-like visor over his clear bubble helmet, clambered onto the ascent engine cover and removed the top hatch. It was, he wrote, "rather as if I was in the conning tower of a submarine or the turret of a tank". Meanwhile, Irwin shaded the instrument panel from the unfiltered lunar sunlight and arranged Scott's oxygen hoses and communications cables to enable him to stand upright. "He offered me a chance to look out," Irwin wrote, "but my umbilicals weren't long enough and I didn't want to take the time to rearrange them."

In the weak gravity, Scott found that he could easily support himself in the hatch on his elbows…and beheld the stunning view of the brown-and-tan Apennines, tinged by the intense golden sunlight, against black sky. Irwin passed up a bearing indicator and a large orientation map, which Scott used to shoot a couple of dozen interconnected stereo pictures of the landing site now officially known as "Hadley Base".

As his eyes adapted, and his mind connected it with months spent examining Lunar Orbiter geology maps, Scott began reeling off the landmarks. There was Pluton and Icarus and Chain and Side—intriguing craters in an area known as the "North Complex"—and on the lower slopes of Mount Hadley Delta was the vast, yawning pit of St. George Crater.

One particularly prominent, rocky landmark which they had dubbed "Silver Spur" in honor of their geology professor, Lee Silver, showed clear evidence of stratigraphy in its flanks.

"The SEVA was a marvelous and useful experience, for a lot of reasons," Scott later explained for the Apollo Lunar Surface Journal. "One of our problems at Hadley was that the resolution of the Lunar Orbiter photography was only 60 feet (18 meters), so they couldn't prepare a detailed map. The maps we had were best guesses and we had the radar people tell us before the flight that there were boulder fields...all over the base of Hadley Delta. So another reason for the stand-up EVA was to look and see if we could drive the Rover, because if there were boulder fields down there, and nobody could prove there were no boulder fields, it changed the whole picture."

The view set his mind at ease; it looked totally unhostile and contradicted pre-flight fears. The "trafficability" as Scott put it, would be excellent.

Back inside Falcon, acutely aware that they were the only inhabitants of Earth ever to visit this barren place, the astronauts removed their suits and set about preparing their evening meal and getting ready for sleep. "Tomato soup was big on the menu, as I recall," Scott wrote. "There was no hot-water supply in the LM, as there was in the command module, so all our meals on the lunar surface were served cold and we soon discovered that there was not really enough to eat, either."

In the coming weeks, they would recommend that more food be carried on Apollo 16 and 17, for walking on the Moon required huge reserves of energy and stamina and would prove to be hungry work.

> "Tomato soup was big on the menu…There was no hot-water supply in the LM…so all our meals on the lunar surface were served cold"

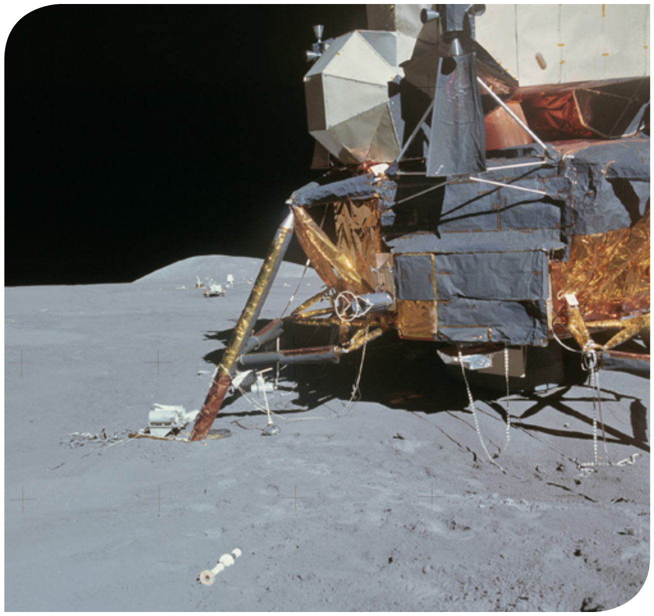
Irwin, too, remembered Apollo 15's staple of soups. "Eating them required some acrobatics," he wrote. "They were…in plastic bags, but they had a Teflon seal that you had to peel off. We added water to the soups, then very carefully pulled the tab to open them up. If you opened them slowly, invariably the soup would start coming out in bubbles or blobs that would float all over the place. The trick was to open the bag fast, so that the viscosity or capillary action would encourage the soup to adhere to the plastic. The object was to take advantage of whatever adhesiveness the soup had." When it had been thus "contained", they could eat quite normally, with a spoon, directing it approximately towards their mouths.

Sleeping in their long johns, without the bulky space suits, was more comfortable in one-sixth gravity than it had been in pre-launch rehearsals. It felt very much like a water bed, Irwin wrote, and they felt as light as feathers in the weak lunar gravity. They popped in earplugs, pulled down the blinds over the two triangular windows and drifted into a fitful sleep. Scott arranged his hammock in a fore-to-aft direction above the ascent engine cover, whilst Irwin stretched "athwart ship".

Despite having long since accepted being here, Scott still succumbed to the temptation to raise the blind and take a long look at the astonishing panorama beyond Falcon's windows, and called on Irwin to come and take a look. There was, however, little time to wonder and the strictness of the timeline forced them to begin preparations to put on their suits for the first of three Moonwalks.

Irwin would subsequently relate, with a hint of humor, that he and Scott did more talking to one another during the donning of the suits than they had in the past several days. With all the added bulk of a backpack, oxygen and water hoses and electrical cabling, and with the suit fully pressurized, Scott found it surprising that he actually fitted through Falcon's small, square hatch when the time finally came to venture outside.

It had become something of a tradition by now for each Apollo commander to make a meaningful comment when he took his first steps on the Moon. Dave Scott's historic handful of words at 9:29 a.m. EDT on 31 July were entirely appropriate for a man who had started out as a fighter pilot and had been steadily won over by the wonders of geology.



Lunar Module Falcon with the Lunar Rover seen behind its left side off in the distance. Credit: NASA via Retro Space Images

"As I stand out here in the wonders of the unknown at Hadley," he said as he gazed in wonderment at the Apennines, "I sort of realize there's a fundamental truth to our nature. Man must explore…and this is exploration at its greatest!"

"As I stand out here in the wonders of the unknown at Hadley, I sort of realize there's a fundamental truth to our nature. Man must explore…and this is exploration at its greatest!"

With a squeeze, and almost falling onto his backside in the lunar dust, Irwin quickly joined Scott and the two men set to work deploying the rover from its berth in Falcon's descent stage. To do so, they tugged on a series of pulleys and braked reels and it required both of them, working in tandem. As it flopped into the lunar dust, the rover was secured with pins.

Scott clambered aboard to give it a test drive and found a minor problem: the front steering was inoperable, so they would have to rely on rear-wheel steering instead. After installing the color television camera and loading up the geology tools, they buckled themselves aboard and set off.

It must have been a peculiar sight for any onlooker to see this space-age dune buggy bouncing across the lunar surface; even at top speeds of just 5-6 mph (8-9.5 km/h), it was a bouncy ride and if the rover hit a rock, it literally went airborne for a couple of seconds. Irwin later likened it to a bucking bronco or an old rowing boat on a rough lake.

"I've never liked safety belts," he wrote, "but we couldn't have done without them on the rover. You could easily get "seasick" if you had any problem with motion." In fact, Irwin's seat belt turned out to be too short and before they could set off Scott had to come around to his side of the rover to buckle him in properly. "We didn't realize," Irwin explained, "when we made the adjustments on Earth, that at one-sixth-G the suit would balloon more and it would be difficult to compress it enough to fasten the seat belt."

The "real" rover was also slightly different to drive than the one in which the men had trained on Earth. From his seat, Scott found that he had to concentrate all of his energies simply driving and keeping track of craters—the harsh glare of sunlight made the terrain appear deceptively smooth, literally "washing-out" surface features, and hummocks and furrows appeared out of nowhere, at a split-second's notice. Its maneuverability was good ("it could turn on a dime," Scott recalled), but its wheels kicked up enormous rooster-tails of dust, which were thankfully deflected by its fenders.

As the navigator, Irwin tried to plot

their course on the map, but had difficulty identifying their route because they were uncertain of precisely where they had set Falcon down.

However, Mount Hadley Delta was clear to see, with St. George Crater—an enormous gouge the size of two dozen football fields—on the lowermost slopes and all they had to do was drive with it on their port quarter and they knew that eventually they would come upon the rille.

Cresting the top of a ridge, they were rewarded with their first unearthly glimpse of Hadley Rille and gained a clear awareness of its enormous size.

Half an hour after leaving Falcon, they made their first scheduled halt at a place called "Elbow Crater", right on the rim of the rille at the base of the mountain. From here, Scott took a series of pictures of the far side of Hadley Rille, whose interior wall showed clear evidence of layering in outcrops not far below its rim, and the two men took a few minutes to gather samples.

Next, they set off towards the rim of St. George Crater. It had been expected that the area would be littered with large blocks of rock, but upon finding the flank of the mountain remarkably clean, Scott decided to halt short of the rim and sample an isolated boulder. It was more than 3.3 feet (1 meter) across and its "half-in-half-out" nature, part-buried in the soft soil.

Simply walking was as strange as the world upon which they were now operating. It felt, Irwin explained, very much like walking on the surface of a trampoline, although the bulk of the space suit made it virtually impossible to move in a natural, Earthly gait. "When you don't have the weight of your legs available to push against the suit," he wrote, "you are constrained as to how far you can move. Consequently, you just use the ball of your foot to push off. That's why we looked like kangaroos when we walked. We flexed the boot and that pushed us forward."

"One of the Moon's most striking features," Scott related, "was its stillness. With no atmosphere and no wind, the only movements we could detect on the lunar surface, apart from our own, were the gradually shifting shadows cast to the side of rocks and the rims of craters by the Sun slowly rising higher in the sky."

There was absolutely no trace of anything which exhibited either life or color or movement and the only sound came from the gentle hum of life-sustaining machinery in their backpacks, the hiss of the air flowing through their suits, or the crackle of each other's voices or the voice of Houston in their earpieces.

The problem of judging distances had been noted by earlier crews. "There's nothing of scale which is familiar," Scott told the *Apollo Lunar Surface Journal*. "There are no trees, there are no cars, there are no houses…and, as an example, we all know what size trees are in general. There are no trees and there's nothing in the landscape that has any familiarity. There's no "hook". So when you

Troubleshooting with a 'dead' astronaut

By Walt Dermody

I was an electronic technician for Grumman Aircraft Co. from 1964 through 1978. One of my duties was to operate the Lunar Module cabin during trouble shooting and testing. Back then, the astronauts spent as much time in and around the hardware as we did.

One day in the MSOB (Manned Spacecraft Operations Building), I was in the cabin by myself working with two headsets on and trouble shooting two different problems with a couple of different engineers.

I forget what systems were in play, but I was about 22 years old at the time just coming out of the Navy and off submarines.

Out of the blue, Jim Irwin sticks his head in the cabin, and asks me if he can come in. Of course I said yes, and then set him up on one of the active channels we were working. I explained to him what we were doing and where we were at in the procedure. He thanked me and proceeded to sit up on the engine cover behind me and follow the tests.

Dave Scott and Jim Irwin in the LM simulator. Credit: NASA via Retro Space Images

After about an hour, the engineers decided to halt testing and shut down the vehicle. I shut down the systems per procedure and turned to tell Mr. Irwin what was going on.

He was sitting on the cover with his arms crossed and his head looking up and eyes closed, I said "Mr. Irwin we are powered down and going to leave." There was absolutely no response.

I proceeded to shake him by the leg. No response. Having never seen anybody do this, I did not realize he had placed himself in a trance. I thought he had died! I was horrified. Luckily at that moment he finally came out of it, and seeing me probably pale by now, explained to me he was meditating. I was glad he was OK, and thankfully no other astronaut did this while I was on watch for the rest of the program.

As was all the Apollo astronauts, Mr. Irwin was a terrific pilot and a perfect gentlemen. It was always a pleasure to have him in the cabin. But at that particular moment in time, I was horrified.

Jim Irwin works at the Lunar Roving Vehicle during the first EVA at the Hadley-Apennine landing site. A portion of the Falcon Lunar Module is on the left. The undeployed Laser Ranging Retro Reflector LR-3 lies atop the LM's Modular Equipment Stowage Assembly MESA. Credit: NASA via Retro Space Images

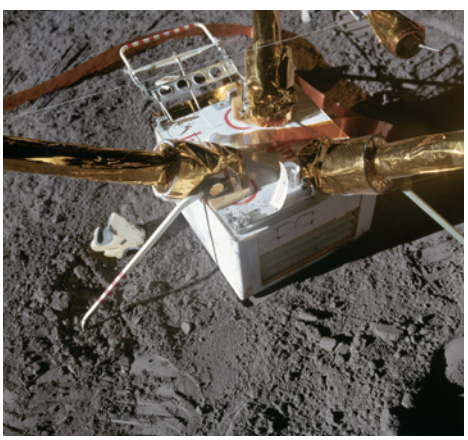
look out there, you see boulders, but you can't really tell whether it's a large boulder at a great distance or a small boulder nearby. If it's very nearby, it's easy because you can run out along the ground and start calibrating your eyes. If you're looking close to the LM, you know what three or four inches are, but as you start going out, you start losing your perspective, because there's nothing to measure out there. It's a very interesting phenomenon that everybody gets fooled on these distances."

Having said this, Scott added that the tracks of the rover lent some indication of distance. "Once you have some tracks," he said, "you can start seeing things. As an example, up on the side of Hadley Delta, looking back at the Lunar Module, boy, it was small!"

In the absence of an atmosphere or the slightest trace of haze, Falcon appeared far closer and far smaller than it actually was. "But it gives you a scale of how far away it is," Scott concluded. Even decades later, Scott expressed frustration with his inability to describe how it felt: the ability of his eyes and how well they transmitted images to his brain was good on the Moon. Yet there was nothing on Earth to compare with it.

Heading back towards Falcon after a little more than two hours, the two men could take great pride in their achievements so far. Yet they still had a sizeable portion of work to do before returning inside. Of primary importance was the assembly of their Apollo Lunar Surface Experiments Package (ALSEP).

Scott picked a spot a few hundred feet from the lander and Irwin lugged it over, one pallet on each end of a carrying bar, not dissimilar to a giant dumbbell. On his cuff checklist, Irwin checked a small "map" of where each component was supposed to go. Meanwhile, Scott was experiencing his own problems.



The Lunar Surface Magnetometer that was part of the mission's Apollo Lunar Surface Experiments Package. Credit: NASA via Retro Space Images

One of the ALSEP's experiments was the heat-flow investigation. This had been assigned to the ill-fated Apollo 13 mission, but never made it to the Moon. It required Scott to use a small, box-like drill to bore a couple of deep holes into the surface and emplace a pair of temperature probes. He would then drill a third hole for a core sample.

He made excellent progress on the first hole, reaching a depth of about 1.6 feet (0.5 meters), then met a hard subsurface. Despite leaning on the drill to give it extra bite, he fell behind schedule and was advised to insert the first set of probes. The second hole proved even more difficult, and Mission Control called a halt with the drill only a couple of feet into the ground. Capcom Joe Allen told Scott to take a breather, then help Irwin with deploying the retroreflector and a solar-wind experiment. They would have to complete the drilling later.

Their first Moonwalk ended slightly earlier than planned, after 6.5 hours.

Back inside Falcon, both men were exhausted. The stress of driving and the toughness of handling the drill for the heat-flow experiment had worn out Scott's hands and forearms. Irwin described the pain in his fingers as excruciating.

They took each other's gloves off to inspect the damage: perspiration poured from them, but there was no evidence of bleeding or bruising. Then they realized that their fingernails, which had grown during the last five days, had been immersed in sweat for the last seven hours. To aid movement, their gloves had been designed to fit tightly against the tips of their fingers; the pressure and the pain was on the ends of the nails.

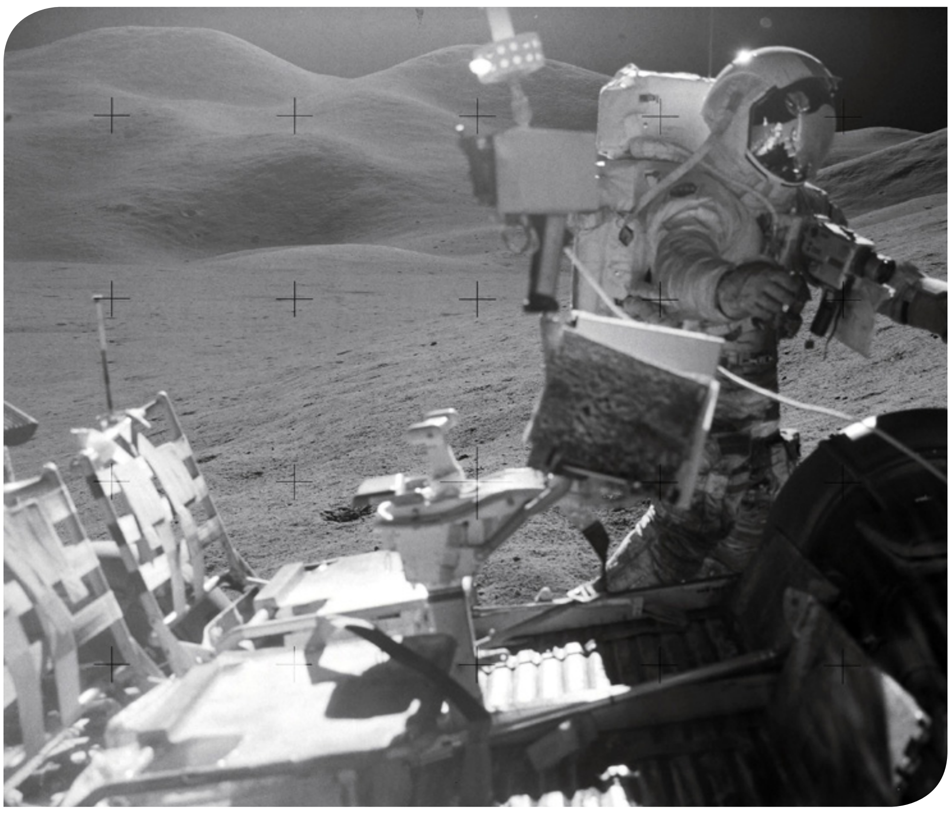
Irwin resolved to cut his nails and advised his commander to do the same, but for some reason—perhaps fearful that it might compromise his own dexterity on the surface—Scott declined.

Irwin was also uncomfortable. A problem with his drinking water bag had left him absolutely parched for more than seven hours. "There was a nozzle that you'd bend down to open a valve so you could suck the water out and drink it within the protection of the space suit," he explained, "but I could never get my drink bag to work and I never got a single drink of water during the whole time I was out on the surface of the Moon." He did, however, manage to gobble down a fruit stick inside his helmet…and that helped him to keep going when the time came to assemble the ALSEP.

Now, having doffed his suit, Irwin guzzled water like a jogger, then settled down with Scott for their second night on the Moon. "Settled" probably was not an appropriate word, for conditions inside Falcon cannot have been pleasant: with the presence of all the rocks and soil specimens, the smell of the Moon—a strong, gunpowder-like aroma—pervaded the air and dust covered everything. They stashed their filthy suits at the back of the cabin, making sure that the gloves were fitted, so as not to impair their seals, then debriefed to Houston and bedded down for their second night's sleep on the Moon.

The next two EVAs would bring tremendous scientific discoveries, which continue to resonate to this day.

Early on 1 August, Capcom Gordon Fullerton woke Scott and Irwin with some unwelcome news. Two days earlier, the lunar module Falcon had touched down at a slight angle—one of its legs had set down in a crater—and this had caused it to lose a sizeable amount of water. Fullerton asked the men to check behind the ascent engine cover. He was right and the astronauts quickly scooped it into a spent lithium hydroxide canister.



During EVA 2, Irwin and Scott collected rock and soil samples, a core sample, and trench samples of an area about 5 km southeast of the Lunar Module. Credit: NASA via Retro Space Images

Scott and Irwin's second Moonwalk was slightly shorter than their first, in order to provide more exploration and less traveling time between geological stops. One relatively low-priority activity had been eliminated and a greater measure of freedom was given to the efforts of the astronauts; Mission Control and the geologists in Houston would depend heavily upon their descriptions and observations and it would be Scott and Irwin's choice on exactly where they chose for their major sampling.

"We're looking now, primarily, for a wide variety of rock samples from the [Apennine] Front," Capcom Joe Allen told them. "You've seen the breccias already. We think there may very well be some large crystal[line] igneous [rocks] and we'd like samples of those and whatever variety of rocks which you're able to find for us—but primarily a large number of documented samples and fragment samples."

Scott was in full agreement; Allen was talking their language and after two years of geological training he felt ready and confident to explore.

A few minutes before 9:00 a.m. EDT on 1 August 1971, safely buckled aboard the lunar rover, the astronauts set off due south, heading for Mount Hadley Delta, upon whose slopes they would concentrate their energies.

It was a scenic trip, Irwin recalled in his memoir, *To Rule the Night*. Ahead of them, and all around them, the terrain was literally splattered with craters, right up the slopes of Hadley Delta, and the height of the mountain rivaled the tallest peaks of the Rockies. After passing the vast cavity of Dune Crater, whose rim was littered with large blocks, they started up the mountain.

On the plain the going had been rough, but on the slope the surface smoothed out markedly. Near Spur Crater, they swung left and drove across-slope.

Looking downslope, they were astonished to realise how far they had come. The lander was a tiny speck on the undulating plain and the astronauts were now at an elevation of about 350 feet (106 meters). The view, completely unhindered by atmosphere or haze, almost knocked Dave Scott's socks off.

Their first task was to find a small "drill hole" crater that could have excavated material from the mountain, but the flank was remarkably clean.

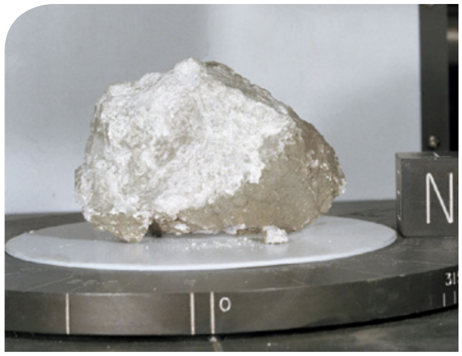
Scott curtailed the planned drive and they sampled a small crater and then an isolated boulder which was coated in greenish material.

The green hue captivated Jim Irwin, whose Irish descent and birthday on St. Patrick's Day—and the fact that he had stowed some shamrocks in the lunar module—made this a special find.

At first, the two men wondered if their eyes or Sun visors were playing tricks on them, but when it was unpacked a few weeks later in the Lunar Receiving Laboratory (LRL), their initial impressions would be confirmed: it was green, made entirely of minuscule spheres of glass, tiny droplets of magma spewed from a fissure by a "fire fountain".

In time, it and other samples would contribute to making Apollo 15 one of the greatest voyages of discovery ever undertaken in human history.

Finally, they headed for Spur Crater. "As soon as we got there," Irwin described, "we could look over and see some of this white rock. Immediately, I saw white, I saw light green and I saw brown. But there was one piece of white rock that looked different from any of the others. We didn't rush over to it; we went about our job the usual way. First I took down-Sun shots and a locator shot about 45 degrees from the Sun-line and Dave took a couple of cross-Sun shots."



A close-up view of the 'Genesis Rock' collected by astronauts Dave Scott and Jim Irwin on the mission's second moonwalk. Credit: NASA

Scott and Irwin slowly threaded their way between the craters to the strange white rock. "It was lifted up on a pedestal," Irwin wrote. "The base was a dirty old rock covered with lots of dust that sat there by itself, almost like an outstretched hand. Sitting on top of it was a white rock almost free of dust. From four feet away I could see unique long crystals with parallel lines, forming striations." Scott used tongs to pick it up and held it close to his visor to inspect it. The rock was about the same size as his fist and even as he lifted it, some of its dusty coating crumbled away…and he saw large, white crystals.

"Aaaahh!" he exulted.

"Oh, man!" added Irwin.

The rock was almost entirely "plagioclase"—an important tectosilicate feldspar mineral used by petrologists on Earth to help determine the composition, origin and evolution of igneous rocks—and from their expeditions into the hills of the San Gabriels, Scott recognized it as "anorthosite", which is the purest form of plagioclase.

For some time, lunar geologists had suspected that anorthosite formed the Moon's original, primordial crust; indeed, data from the unmanned Surveyor 7 lander had suggested its presence in the ejecta of the crater Tycho and tiny fragments of it had actually been found in samples from both Apollo 11's landing site at Tranquility Base and Apollo 12's site in the Ocean of Storms.

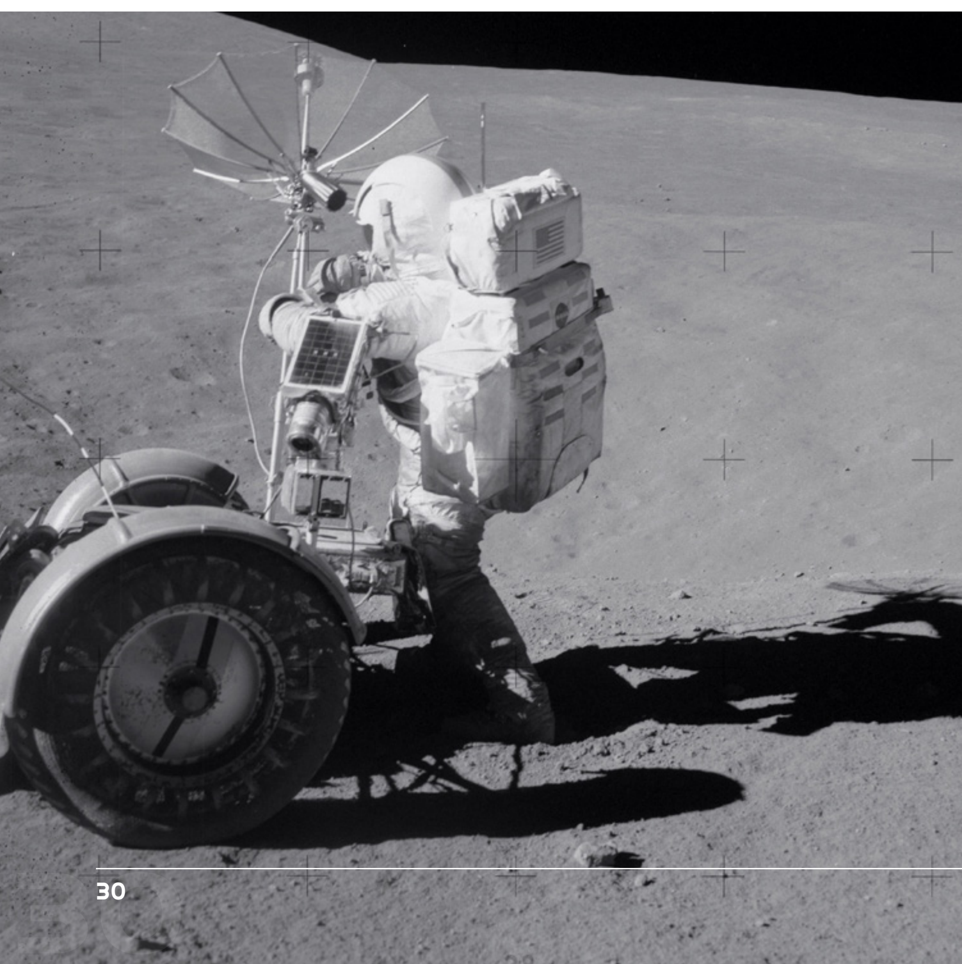
"Explaining why most of the Moon's crust should be composed of anorthosite," wrote Andrew Chaikin in *A Man on the Moon*, "led some geologists to an extraordinary scenario. Within the infant satellite, they proposed, there was so much heat that the entire outer shell became an ocean of molten rock. As this "magma ocean" cooled, minerals crystallized. The heavier species, including the iron- and magnesium-rich crystals, sank to the bottom. The lighter crystals, specifically, the mineral [aluminium-rich] plagioclase floated to the top."

Recognizing the find as probably a piece of the Moon's primordial crust, Scott could hardly contain his enthusiasm. "Guess what we just found!" he radioed. "I think we just found what we came for!"

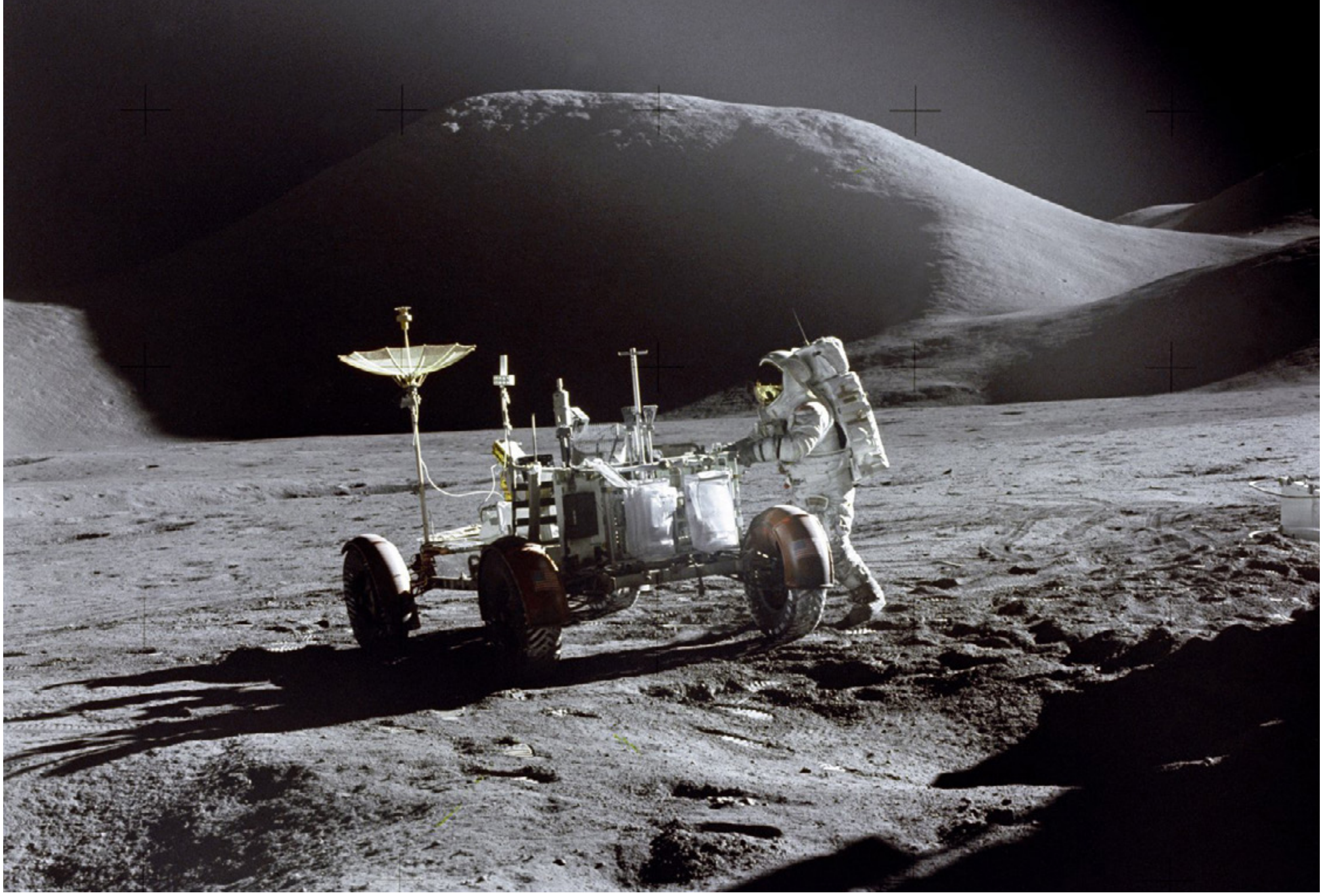
"Crystalline rock, huh?" said Irwin.

"Yessir," replied Scott.

After briefly describing the rock's



Working at Spur Crater during the second EVA. Credit: NASA via Retro Space Images



Jim Irwin is photographed beside the Lunar Roving Vehicle, with Mount Hadley in the background. Seen on the back of the Rover are two sample collection bags mounted on the gate, along with the rake, both pairs of tongs, the extension handle with scoop probably attached, and the penetrometer. Credit: NASA

appearance, Scott placed it into a sample bag by itself. It would be labeled as sample number 15415, but a keen journalist, inspired by the term "petrogenesis", the study of the origin of igneous rocks, would later offer it a far more lofty title: "The Genesis Rock", a sample of the original lunar crust, coming from one of the earliest epochs of the Moon's history, some 4.1 billion years ago.

This date was reached by geologists at the University of New York at Stony Brook and proved to be almost 1.5 billion years older than the oldest rocks found on Earth. If the Moon was any older than that, noted Chaikin, it wasn't much older; the Solar System itself was thought to have formed only a few hundred million years earlier.

Back in the vicinity of Falcon, shortly before 2:00 p.m. EDT and five hours into their second Moonwalk, Scott and Irwin had other chores to finish; first, there was the need to complete drilling the heat-flow hole which had hit resistant soil the previous day.

Scott had already noticed inside the lander that his injured fingers were starting to turn black and so had to summon as much strength as he could muster—bringing his hands right up close to his chest just to squeeze the drill's trigger—to complete the task. He could physically stand only about a minute of the pressure on his fingernails, before breaking off for a breather. At length, both sensor packages were in place to a depth of about 5 feet (1.5 meters).

However, when Scott attempted to extract the core sample which, at about 8 feet (2.4 meters) long, was the deepest such sample yet attempted on the Moon, he managed to lift it slightly, but it refused to budge any further. Joe Allen told him to leave it until tomorrow's final excursion.

Meanwhile, Irwin dug a trench and used a penetrometer to test the bearing strength of its walls and floor. "If you think digging a ditch is dog's work on Earth," he wrote, "try digging a ditch on the Moon. The big limitation is the suit and the fact that you are clumsy at one-sixth-G. I had practiced on Earth and come up with a technique that most dogs use. You spread your legs and push the dirt between them. I solved a dog's job with a dog's technique. This method worked perfectly on the Moon."

He easily dug through a fine grey material which he likened to talcum powder, and then a coarser, darker soil, but had to give up on reaching a very resistant layer which, although it looked moist, had all the consistency of hardpan.

They wrapped up the second Moonwalk by planting the American flag and loading that day's rock box aboard Falcon. Not only had most of the equipment operated flawlessly, but the live—and color—images provided by the Earth-operated television camera on the rover was a far cry from the crude black-and-white pictures of Apollo 11.

Furthermore, Scott and Irwin had truly done their mentor, Lee Silver, proud through their geological descriptions. "I'm told," Joe Allen

The leaning Falcon rests on on the lunar surface. Irwin took this photo at the start of the third EVA.
Credit: NASA via Retro Space Images

radioed, "that we checked off the 100-percent science completion square time during EVA-1 or maybe even shortly into EVA-2. From here on out, it's gravy all the way!"

The gravy of the third excursion would be tempered by the fact that it would also be the shortest, scheduled to last barely four and a half hours. It started with the recovery of a core sample from EVA-1. For a few moments, their efforts to extract the core tube from the ground were fruitless and Scott was almost ready to give up. However, with Irwin's persuasion, both men hooked an arm under each handle of the drill and after several firm tugs the tube sprang from the ground.

Precious minutes were wasted, though, when the vice carried on the rover to dismantle the tube into storable sections proved to have been fitted backwards; Irwin broke out a wrench and used that, but Scott's frustration was evident. He knew that for every minute wasted before the drive started, they would lose at least another two minutes of geological exploration.

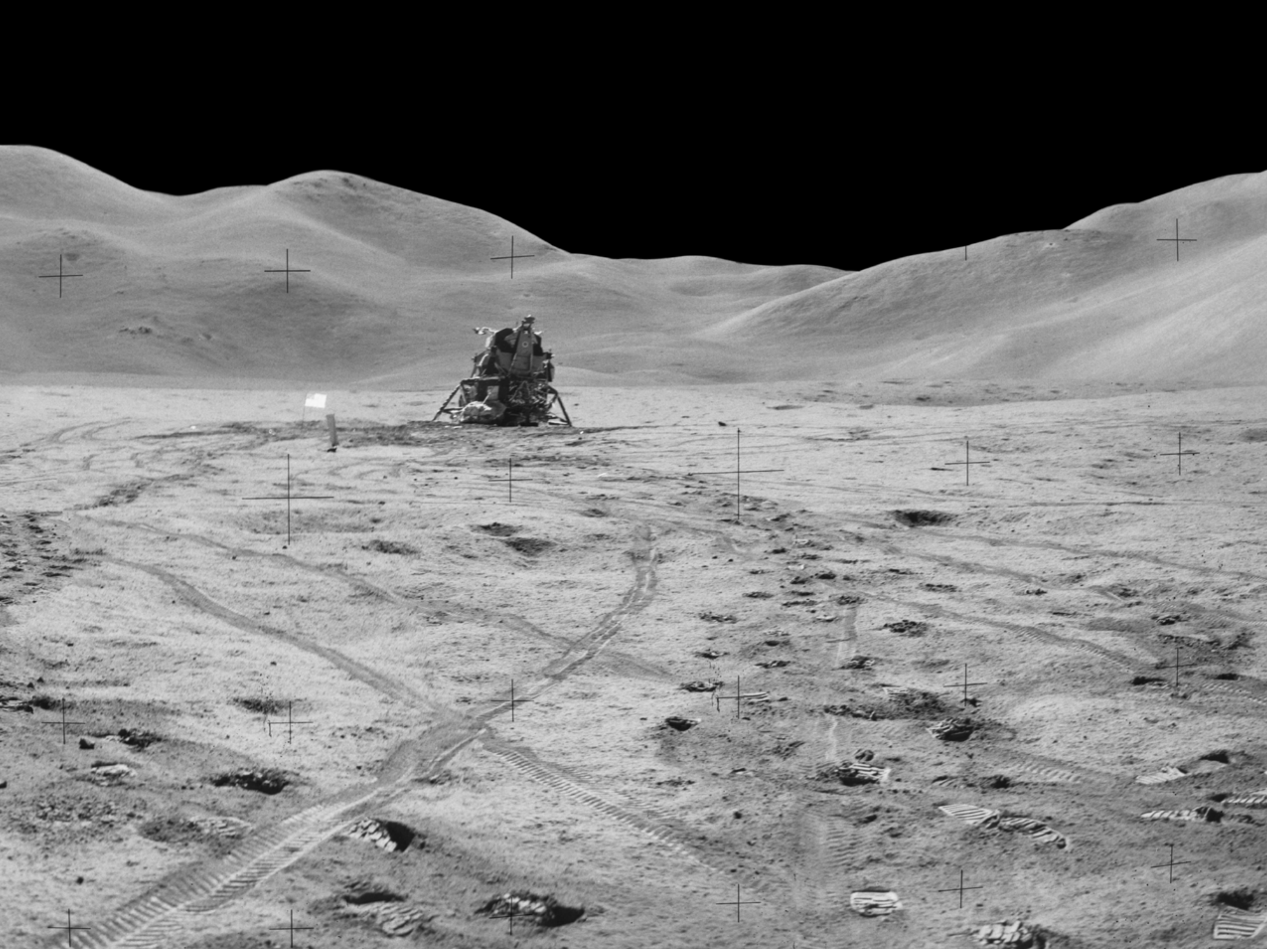
Some of the senior NASA managers in Mission Control wanted to abandon the core entirely. However, the astronauts and Joe Allen had an ally in Flight Director Gerry Griffin, who had shared several of their geological trips in the California mountains and knew how important the science was…and how important the deep core sample was to the success of this mission. It was he who persuaded the managers not to abandon the core tube work.

After they had partially disassembled the tube, it was decided that they should leave the remainder of the task to later. When the core was finally opened on Earth, it proved to contain several dozen layers which documented some 400 million years' worth of lunar history...

At length, Scott and Irwin buckled into the rover and headed west-northwest for a good look at Hadley Rille. After the rille, if time permitted, they hoped to grab an opportunity to inspect the mysterious "North Complex" of craters, which some geologists thought might be a cluster of small, ancient volcanoes.

Their arrival at Hadley Rille was truly breathtaking. Its far wall, bathed in the harsh, direct sunlight of the late lunar morning, showed distinct layers of rock pushing through a mantle of dust, lending credence to theories that Mare Imbrium had been built up as a succession of ancient lava flows.

One theory was that the rille was



a fracture where the mare surface "opened" like a cooling joint. "But since the scientists have studied the pictures," Irwin wrote, "the most popular theory is that Hadley Rille was probably a lava tube that collapsed."

All around the two men were enormous slabs of basalt and the geologists in the back room in Houston quickly began pressing for them to move further downslope, though Joe Allen was becoming nervous. Looking at televised pictures, it seemed to him as though they were right on the edge of a precipice.

In fact, the rille had no dramatic "drop"; rather, it resembled the gentle shoulder of a hill, and they were able to walk downslope without difficulty. "In fact," Scott wrote, "the slope down which we descended was only about 5-10 degrees and the maximum slope of the rille was only 25 degrees—not steep for such a canyon-like formation." It was steep enough, however, that from their vantage point they were unable to see the floor.

"We checked off the 100-percent science completion square time during EVA-1 or maybe even shortly into EVA-2. From here on out, it's gravy all the way!"

Time was escaping them (it was "relentless", Apollo 15 backup commander Dick Gordon once said), and any chance to explore the North Complex very quickly disappeared; that would have to await another generation.

Both astronauts found this bitterly disappointing: in Irwin's mind, it left their excursion only half-complete, whilst Scott would wonder for years afterward if the unique data from the deep core was really worth abandoning the chance to visit the North Complex. At the same time, they appreciated the urgent need to get back to Falcon with enough time to prepare for liftoff later that day.

Back at the lander, with the minutes of the final Moonwalk rapidly winding down, Scott had one last opportunity to give a scientific demonstration to an audience of millions back home. It came from a suggestion by Joe Allen, who was inspired by the experimental work of the great Italian scientist, Galileo Galilei.

More than three centuries earlier, Galileo had stood atop the Leaning Tower of Pisa and dropped two weights of different sizes, proving that gravity acted equally on them, regardless of mass.

Now, in front of his own Leaning Tower—the slightly-tilted Falcon—Scott performed his own version of the experiment.

"In my left hand, I have a feather," he told his audience, "in my right hand, a hammer. I guess one of the reasons we got here today was because of a gentleman named Galileo a long time ago, who made a rather significant discovery about falling objects in gravity fields. The feather happens to be, appropriately, a falcon's feather, for our Falcon, and I'll drop the two of them here and hopefully they'll hit the ground at the same time."

They did…and applause echoed throughout Mission Control.

"How about that?" Scott concluded triumphantly. "Mr Galileo was correct in his findings!" He originally planned to try it first, to check that it would work, but was worried that it might get stuck to his glove. He decided to "wing it" and, thankfully, it worked.

In his autobiography, Irwin would relate that Scott had actually carried two feathers on Apollo 15, one from the falcon mascot at the Air Force Academy. Unfortunately—and much to Scott's irritation—Irwin accidentally stepped on it! They searched for the feather, but could only find his big bootprints. "I'm wondering," wrote Irwin, "if hundreds of years from now somebody will find a falcon's feather under a layer of dust on the surface of the Moon and speculate on what strange creature blew it there."

Shortly after 9:00 p.m. EDT on 2 August, a little more than four hours since setting foot on the surface for EVA-3, Scott drove the rover, alone, to a spot a few hundred feet east of the lander.

From this place, Mission Control

The Apollo 15 spacecraft was modified to carry out a greater range of lunar orbital science activities than any previous mission. Credit: NASA

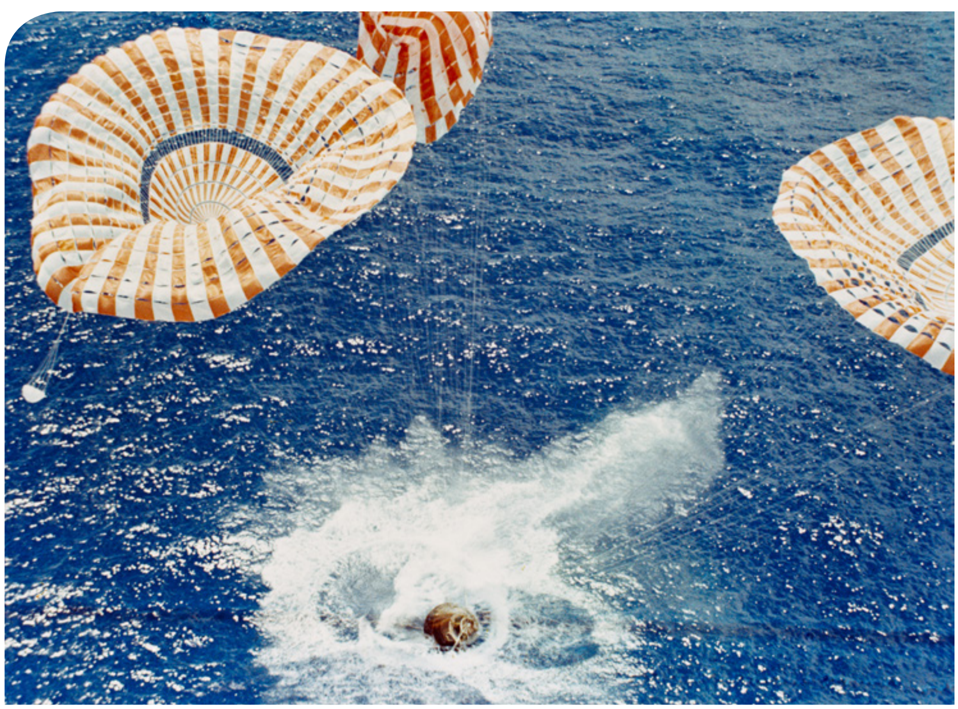
would be able to remotely operate its television camera to record the liftoff of Falcon's ascent stage. Scott pulled out a small red Bible and placed it atop the control panel of the rover, in order to show those who followed in their footsteps why they had come.

Next, he climbed off the machine and strode toward a small crater. He dug a small hollow and dropped a small aluminum figurine of a fallen astronaut onto the lunar soil. The tiny figurine had been arranged by Apollo 15 command module pilot Al Worden. Meanwhile, Jim Irwin had organized a small plaque, planted alongside, listing the names of 14 astronauts and cosmonauts known to have died doing their duty. The list included Yuri Gagarin, the first man in space, together with Vladimir Komarov and the crews of Apollo 1 and Soyuz 11.

As he gazed on the plaque, Scott knew he would never come here again. "I had come to feel a great affection for this distant and strangely beautiful celestial body," he later wrote in his memoir, Two Sides of the Moon. "It had provided me with a peaceful, if temporary, home. But it was time to return to my own home back on Earth."

Within the confines of Falcon, they had little time to gaze out at the spectacular site of Hadley; only a few hours remained before their 1:11 p.m. EDT liftoff, bound for a rendezvous with Al Worden in the command module Endeavour.

It marked the first occasion on which a crew would complete a moonwalk and perform the liftoff and rendezvous without a rest period in between the two. Having been outside for less than five hours



The Apollo 15 Command Module safely touches down in the mid-Pacific Ocean even though one of the three main parachutes failed to function properly. Credit: NASA

A wide-angle, overall view of the Mission Operations Control Room in the Johnson Space Center Mission Control Center taken after recovery of the Apollo 15 crew aboard the USS Okinawa. Credit: NASA via Retro Space Images

on EVA-3, Irwin wished that Mission Control could have postponed the inevitable by several hours to have enabled them to drive home by way of the North Complex and gather a few samples. Sadly, it was not to be.

Precisely on time, Scott punched the Abort Stage button and a television audience back on Earth had the chance to actually see an Apollo crew leave the Moon. Falcon's ascent stage literally "popped" away from the descent stage and shot directly upwards with all the speed and accuracy of an express elevator, spraying a shower of fragments of insulation radially outwards.

One journalist would later compare it to something left over from a Fourth of July celebration. Watching from Mission Control, Chris Kraft—then serving as deputy director of the Manned Spacecraft Center (MSC), today's Johnson Space Center (JSC) in Houston, Texas—would gape at the speed of the departure. "I had no idea it went so fast," he wrote in his autobiography, *Flight*. "We'd been told it was like that by the other Moon crews, but seeing it for real was a thrilling shock."

Ten seconds later, a strangely familiar sound came into Scott and Irwin's earpieces: The Air Force Song, courtesy of Worden, which they had intended to play to Houston only, but which somehow ended up being routed to Falcon, as well. "This was kind of surprising," wrote Irwin, "because Dave had briefed Al to turn on that music at one minute after liftoff (that first minute is rather critical) but here it came at ten seconds. It really caused some consternation in Houston. First, they thought somebody was playing a trick in Mission Control, so they conducted a big search. They asked for radio silence – it was a tense situation. Finally, they realised that probably we had turned it on."

Falcon's ascent stage literally "popped" away from the descent stage and shot directly upwards with all the speed and accuracy of an express elevator, spraying a shower of fragments of insulation radially outwards.

Several days later, on 7 August, Endeavour splashed down safely in the waters of the Pacific Ocean, bringing the lunar explorers safely back to Mother Earth.

The months which followed would be challenging for them all. Initially assigned as the backup crew for Apollo 17 – the final lunar landing mission – they were abruptly removed from flight status in April-May 1972 and replaced by John Young, Stu Roosa and Charlie Duke. The reason stemmed from their carriage of four hundred unauthorised first-day covers, the proceeds of which were to be invested into trust funds for their children.

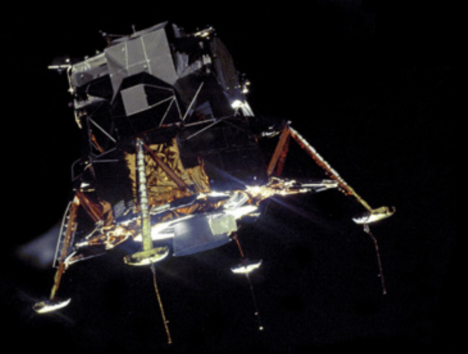
Although the agreement with a German stamp dealer went awry within weeks of splashdown and none of the Apollo 15 astronauts accepted any money, they were harshly criticised by NASA and some members of Congress, who demanded an investigation into "improper conduct". Although none of them had done anything wrong or illegal, they were stripped of flight status and Scott fumed that NASA did nothing to dispel (untrue) rumours that they had been fired.

Forty-four years after the remarkable scientific extravaganza of Apollo 15 – a mission which unveiled more of the Moon's mysteries than ever before – it is saddening that this incident continues to resonate.

However, the exploration of Dave Scott, Al Worden and Jim Irwin serves one other purpose: to whet the appetites of future lunar explorers, awaiting their chance to visit the mountains of the Moon once again.

S.T.E.M. for the Classroom

The thrill(e) on the Rille



Vocabulary

- **Depth:** How deep the rille is.
- **Distance:** How far from the edge of the rille to its center.
- **Rille:** A collapsed lava tube that resembles a small canyon.
- **Rope Length:** The amount of rope needed to descend Hadley Rille.
- **Rope Weight:** The mass of the rope per standard length.
- **Slope:** The angle the rille wall makes to the horizontal.

Narrative

Apollo 15 landed near Hadley Rille in the Apennine Mountains of the Moon back in 1971. It has been heralded as the most scientifically robust of all the Apollo expeditions. Its Commander, Dave Scott, and Lunar Module Pilot, Jim Irwin, were indeed true explorers. They had even wanted to take a sample of rocks from the bottom of the rille. The idea was to tie a rope to Scott with Irwin acting as an anchor. Scott would shimmy down the slope of the rille while Irwin would play out the line. It was considered a dangerous plan with a high scientific return.

It was not approved.

But what if NASA had said yes? How much rope would Scott have needed? How much would the rope have weighed? And what was the slope of the rille that the Commander would have had to traverse?

Analysis

NASA studied the Moon prodigiously before going there, and took great pains to select each precious landing site. Thus, Hadley Rille was fairly well known geographically.

To solve this hypothetical problem, we use basic trigonometry. The hypotenuse of the triangle is the length of rope needed for the traverse, the adjacent side is the Distance, and the opposite side is the Depth. The slope is the angle between the hypotenuse and the adjacent side. Dashed lines are provided to help with the measurements.

For a more in-depth treatment of this high school project by Joe Maness & Rich Holtzin visit www.stemfortheclassroom.org.

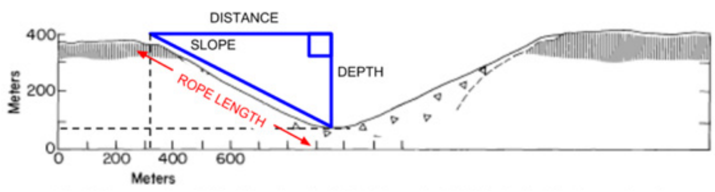


Fig. 3. Cross section of the rille at Apollo 15 site (at station 10). Vertical ruling is mare basalt; triangles are talus deposits. Scale in meters. Topography by R. M. Batson, in Swann *et al.*, 1972.

The length of the rope can be found using the Pythagorean Theorem:

$$hypotenuse^2 = adjacent^2 + opposite^2 \Rightarrow hypotenuse = \sqrt{adjacent^2 + opposite^2}$$

$$Rope\ Length = \sqrt{Distance^2 + Depth^2}$$

A one-half-inch diameter nylon rope weighs in at 100 grams per meter, or 0.1 kg/m. Therefore,

$$Rope\ Weight = Rope\ Length \cdot \frac{0.1\ kg}{m}$$

The Slope can be found using one of the trigonometric identities. Since we are given the opposite (Depth) and the adjacent (Distance) sides, we can use the tangent ratio.

$$\tan(angle) = \frac{Opposite}{Adjacent} \Rightarrow angle = \tan^{-1}\left(\frac{Opposite}{Adjacent}\right)$$

$$Slope = \tan^{-1}\left(\frac{Depth}{Distance}\right)$$

We're assuming that a gradient of anything less than 45° is within acceptable limits.

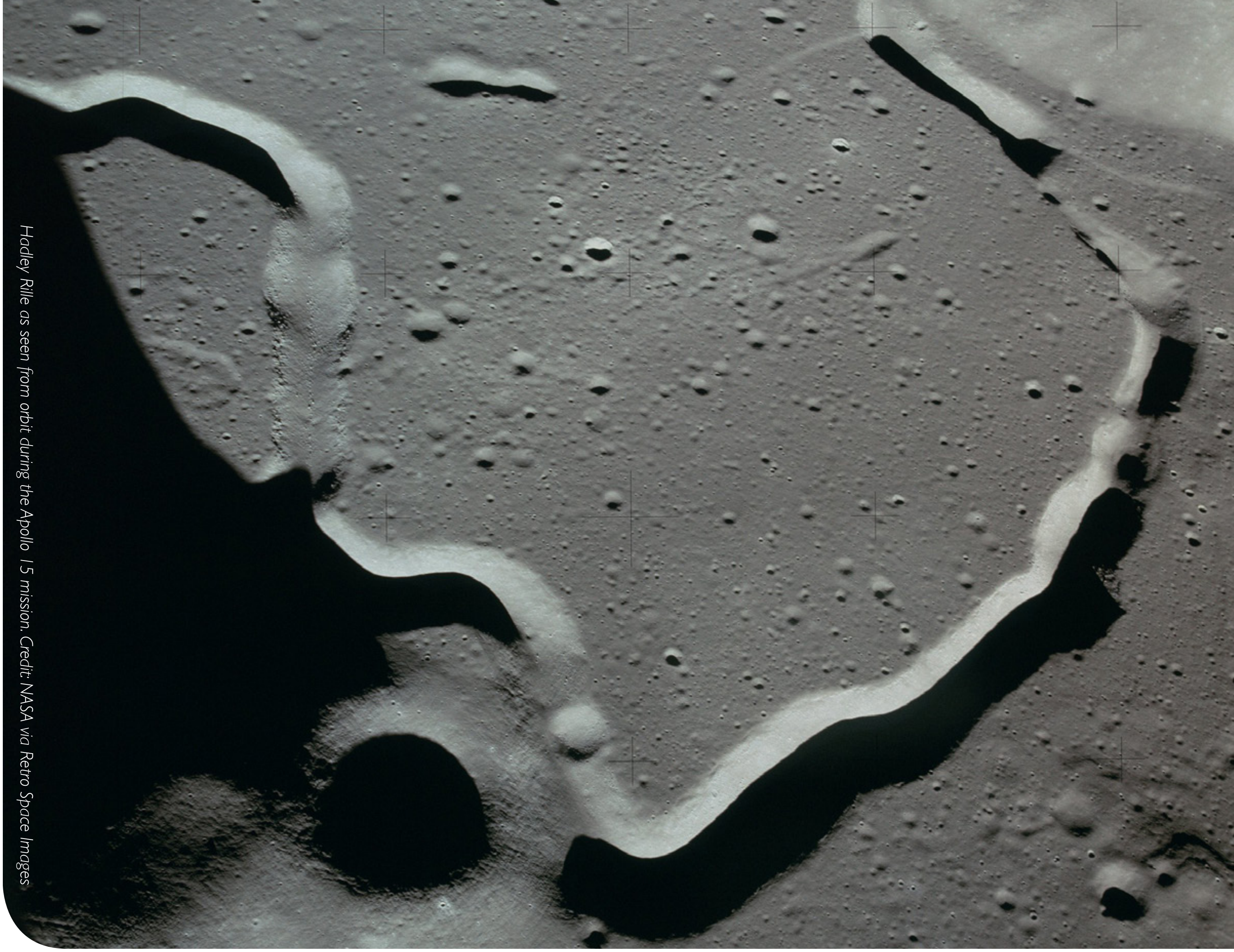
Example

In an alternate universe, NASA decided to go ahead with the endeavour into the maw of Hadley. How much rope was needed for this wild and crazy idea, how much was the weight of said rope, and what was the slope of the rille that the Commander would have negotiated?

From the NASA image, the Distance and Depth can be determined.

Distance = 950 - 320
= 630 m

Depth = 380 - 80
= 300 m



Hadley Rille as seen from orbit during the Apollo 15 mission. Credit: NASA via Retro Space Images

Therefore, the length of rope needed is

$$Rope\ Length = \sqrt{Distance^2 + Depth^2}$$

$$= \sqrt{630^2 + 300^2}$$

$$= \sqrt{486,900}$$

$$= 697.78\ m$$

The weight of the rope is

$$Rope\ Weight = Rope\ Length \cdot \frac{0.1\ kg}{m}$$

$$= 697.78\ m \cdot \frac{0.1\ kg}{m}$$

$$= 69.78\ kg$$

In other words, the rope is almost 2,300 feet long and weighs over 150 pounds!

The slope of the rille face is

$$Slope = tan^{-1}(\frac{Depth}{Distance})$$

$$= tan^{-1}(\frac{300}{630})$$

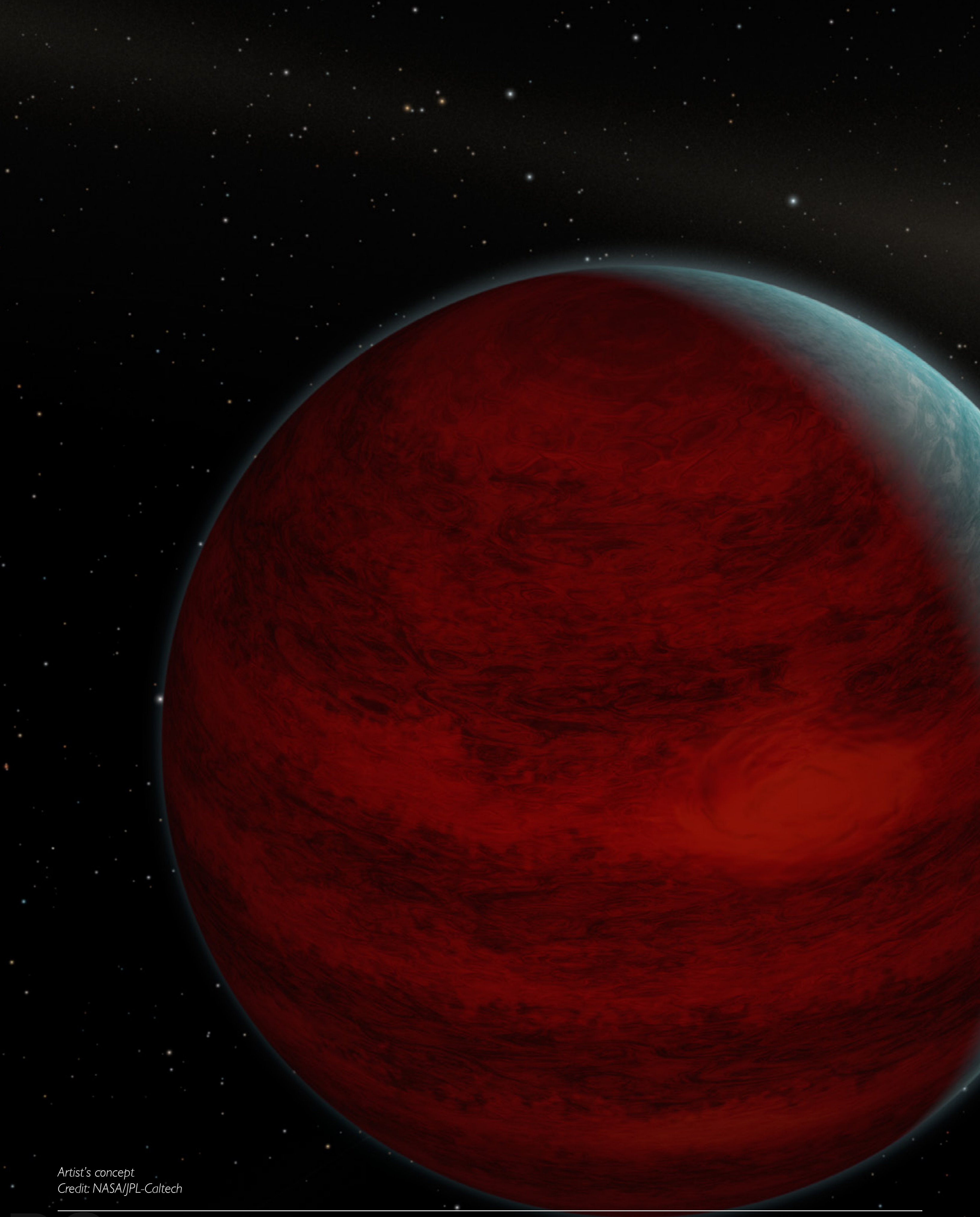
$$= tan^{-1}(0.476)$$

$$= 25.46^o$$

Conclusion

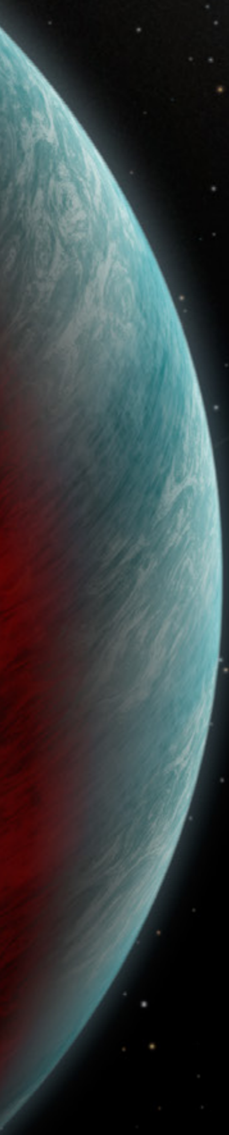
The slope being way less than 45° implies that there would not have been too much of a problem traversing it, especially in a one-sixth Earth gravity environment. However, even though the trip to the bottom and back was technically feasible and scientifically desirable, we're not quite sure it would have been worth the 70 kilograms (yikes!) of rope needed to complete the journey.

Maybe NASA made the right call after all?



Artist's concept
Credit: NASA/JPL-Caltech

Planets may rejuvenate around dead stars



For a planet, this would be like a day at the spa. After years of growing old, a massive planet could, in theory, brighten up with a radiant, youthful glow. Rejuvenated planets, as they are nicknamed, are only hypothetical. But new research from NASA's Spitzer Space Telescope has identified one such candidate, seemingly looking billions of years younger than its actual age.

"When planets are young, they still glow with infrared light from their formation," said Michael Jura of UCLA, coauthor of a new paper on the results in the June 10 issue of the Astrophysical Journal Letters. "But as they get older and cooler, you can't see them anymore. Rejuvenated planets would be visible again."

How might a planet reclaim the essence of its youth? Years ago, astronomers predicted that some massive, Jupiter-like planets might accumulate mass from their dying stars. As stars like our sun age, they puff up into red giants and then gradually lose about half or more of their mass, shrinking into skeletons of stars, called white dwarfs. The dying stars blow winds of material outward that could fall onto giant planets that might be orbiting in the outer reaches of the star system.

Thus, a giant planet might swell in mass, and heat up due to friction felt by the falling material. This older planet, having cooled off over billions of years, would once again radiate a warm, infrared glow.

The new study describes a dead star, or white dwarf, called PG 0010+280. An undergraduate student on the project, Blake Pantoja, then at UCLA, serendipitously discovered unexpected infrared light around this star while searching through data from NASA's Wide-field Infrared Survey Explorer, or WISE. Follow-up research led them to Spitzer observations of the star, taken back in 2006, which also showed the excess of infrared light.

At first, the team thought the extra infrared light was probably coming from a disk of material around the white dwarf. In the last decade or so, more and more disks around these dead stars have been discovered – around 40 so far. The disks are thought to have formed when asteroids wandered too close to the white dwarfs, becoming chewed up by the white dwarfs' intense, shearing gravitational forces.

Other evidence for white dwarfs shredding asteroids comes from observations of the elements in white dwarfs. White dwarfs should contain only hydrogen and helium in their atmospheres, but researchers have found signs of heavier elements – such as oxygen, magnesium, silicon and iron – in about 100 systems to date. The elements are thought to be leftover bits of crushed asteroids, polluting the white dwarf atmospheres.

But the Spitzer data for the white dwarf PG 0010+280 did not fit well with models for asteroid disks, leading the team to look at other possibilities. Perhaps the infrared light is coming from a companion small "failed" star, called a brown dwarf – or more intriguingly, from a rejuvenated planet.

"I find the most exciting part of this research is that this infrared excess could potentially come from a giant planet, though we need more work to prove it," said Siyi Xu of UCLA and the European Southern Observatory in Germany. "If confirmed, it would directly tell us that some planets can survive the red giant stage of stars and be present around white dwarfs."

In the future, NASA's upcoming James Webb Space Telescope could possibly help distinguish between a glowing disk or a planet around the dead star, solving the mystery. But for now, the search for rejuvenated planets – much like humanity's own quest for a fountain of youth – endures.

Starting in astronomy

beginner's guide to stargazing

By Mike Barrett

Clusters of jewels in the night sky

Stellar Clusters are groups of stars that fall into two broad categories: Open Clusters or Globular Clusters. Both types of cluster are formed from gas clouds and dust coalescing into a multitude of stars, but this is where the commonality ends.

Open Clusters

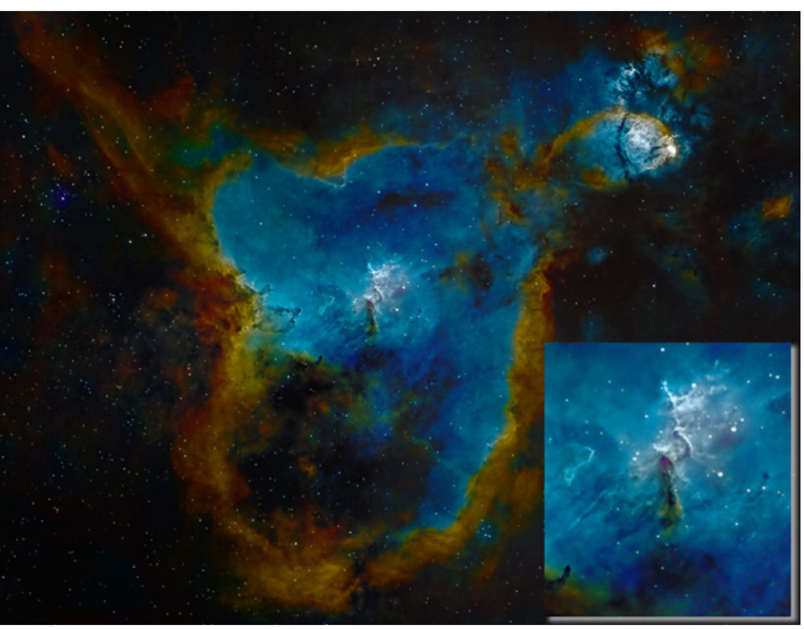
Open Clusters can contain up to a thousand stars which are normally very young, in cosmic terms. They are generally found in the stellar nurseries of the spiral arms of the galaxy. As the Open Clusters contain young stars they are often hot stars, blue to white in color.

Some Open Clusters appear to to the eye as just a collection of disassociated stars. A typical example of this would be the Beehive Cluster, M44, in Cancer. This is an example of an older Open Cluster where the gasses and dust have either been ejected or incorporated into the cluster members. These may even have some older orange stars in the group and be very spread apart like the Hyades in Taurus. I spent ages when I first started in astronomy looking for the Hyades Cluster, not realising how big it was and how far apart its members were.

Middle-aged Open Clusters such as the Pleiades or M45 have bright blue stars of spectral type B. Although the Pleiades stars are surrounded by blue nebulosity this is reflection nebulosity in interstellar matter rather than the gaseous remains of the stellar nursery. The Pleiades are a very visible cluster to the naked eye, even from areas with heavy light pollution. They form a question mark in the winter skies of the northern hemisphere.

Young Open Clusters can be found within the heart of the star generating nebulae, such as the Heart Nebula (IC1805) , and the Orion Nebula (M45). These are surrounded by gasses and stellar dust. The gas is predominantly hydrogen giving these nebulae the characteristic red color.

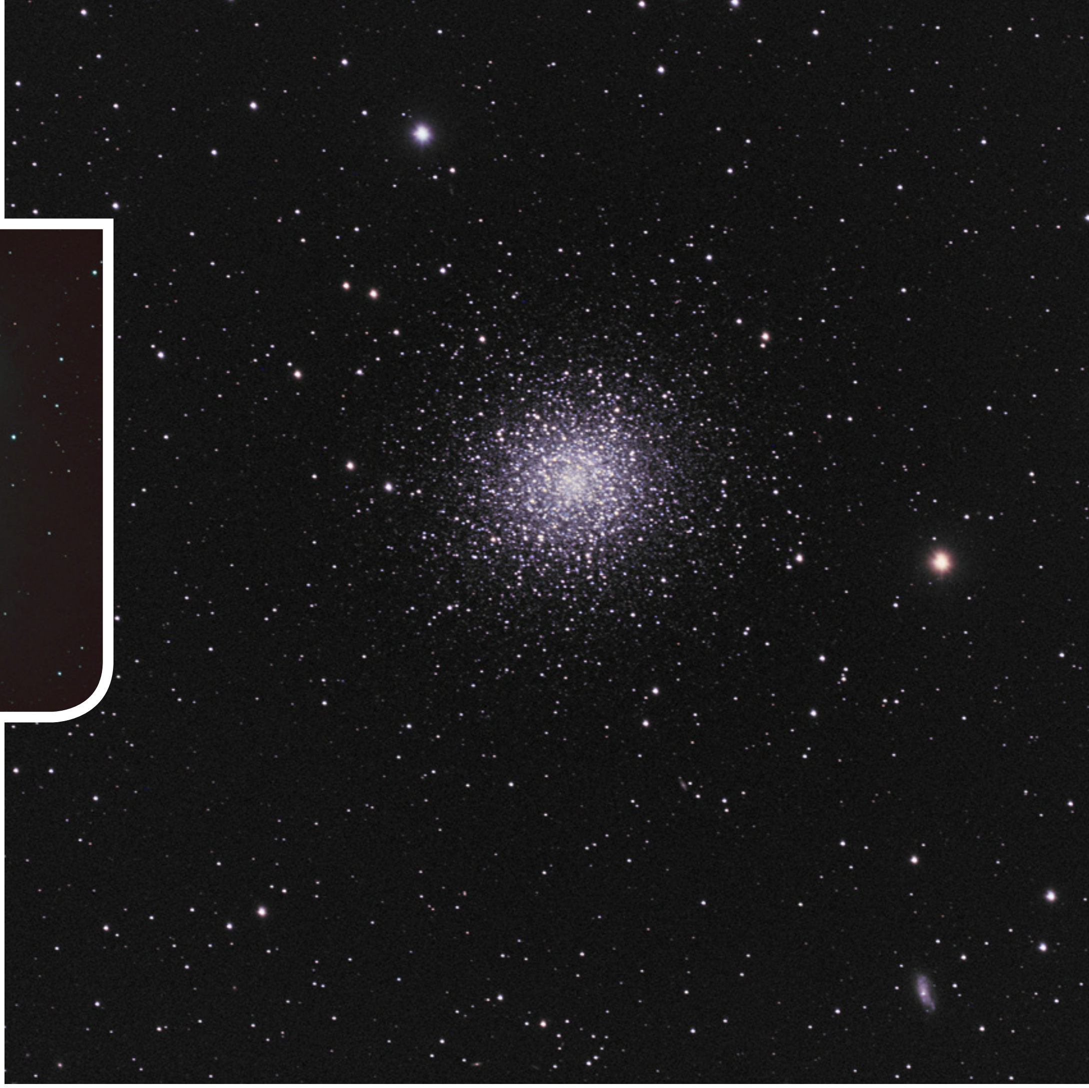
The Heart Nebula actually has a number of Open Clusters associated with it, the main one having the same name as the entire nebula. This is found in the Heart of the Heart at the top of a pillar of gas.The dramatic coloring of the heart nebula image is because the data was captured using narrowband filters and creating a false color final result.



Star Cluster (above) at the center of the Heart Nebula IC1805.
Credit Dave Smith www.AstroSnaps.co.uk

M45 the Pleiades (right), an open cluster visible to the naked eye.
Credit: Mike Barrett

M42 the Orion Nebula (above). At the center of the bright area is the Trapezium Cluster. Credit: Mike Barrett



M13, the Great Globular Cluster in Hercules
Credit: Mike Barrett

Within the center of the Orion Nebula, M42, is an area known as the Trapezium Cluster. The Trapezium Cluster contains just a few stars, but they are very bright and very hot. They shine through the nebula and can be easily seen in a small telescope.

Globular Clusters

Globular Clusters are categorised by the number of stars in the group ranging from a few thousand to many millions of individual stars. These are all congregated in a relatively small area and are bound together by gravity. Most Globular Clusters exist outside the main ecliptic of the galaxy in the halo of the galaxy and orbit the galactic core.

In contrast to the Open Clusters the Globular Clusters are formed from very old stars and will typically be seen ranging from white to orange in color. The predominant star type in a Globular cluster is spectral type G which is the same as our Sun. There can still be some younger stars in the cluster, but images will mainly show white and orange stars.

There are around 150 Globular Clusters orbiting our galaxy. The precise number of the Globular Clusters is difficult to ascertain as they are not all visible so the quantity has been estimated based on the number of observable clusters. Globular Clusters are not unique to our galaxy, we can observe similar star clusters orbiting other galaxies.

The best examples of Globular Clusters are M13: The Great Globular Cluster in Hercules, and Omega Centauri in Centaurus. Both of these can be seen in dark skies without a telescope. M13 is a classic northern hemisphere object visible throughout summer and autumn. Omega Centauri is visible from more southerly sites, and in the southern hemisphere.

To the naked eye the clusters will appear like a faint fuzzy blob, not dissimilar from a galaxy. When viewed with binoculars the circular form can be observed, without a distinct edge. Telescopes reveal more of the structure of the cluster, including some of the individual stars in the core extending out to the diffuse stars of the extremities. As with all astronomical observations of faint objects the real detail and beauty of these clusters is revealed in astrophotography. Using the technique of combining a number of long exposures and careful processing the structure and form of the cluster can be teased out.

Good luck hunting for these star clusters, the best ones to look for in the summer are M13 in the Northern Hemisphere and Omega Centauri in the Southern Hemisphere.

Omega Centauri

This issue it was a coin toss for the spotlight object between The Great Globular Cluster in Hercules and Omega Centauri. Omega Centauri won as it is the largest by far of the Globular Clusters and it has the potential to be seen by more people in both hemispheres. It is visible in Southern Europe and the United States but is quite low in the southern skies at best. In Australia Omega Centauri rises high in the night skies during the summer months.

VST image of the giant globular star cluster Omega Centauri.
Credit: ESO/INAF-VST/OmegaCAM

More astronomy lessons

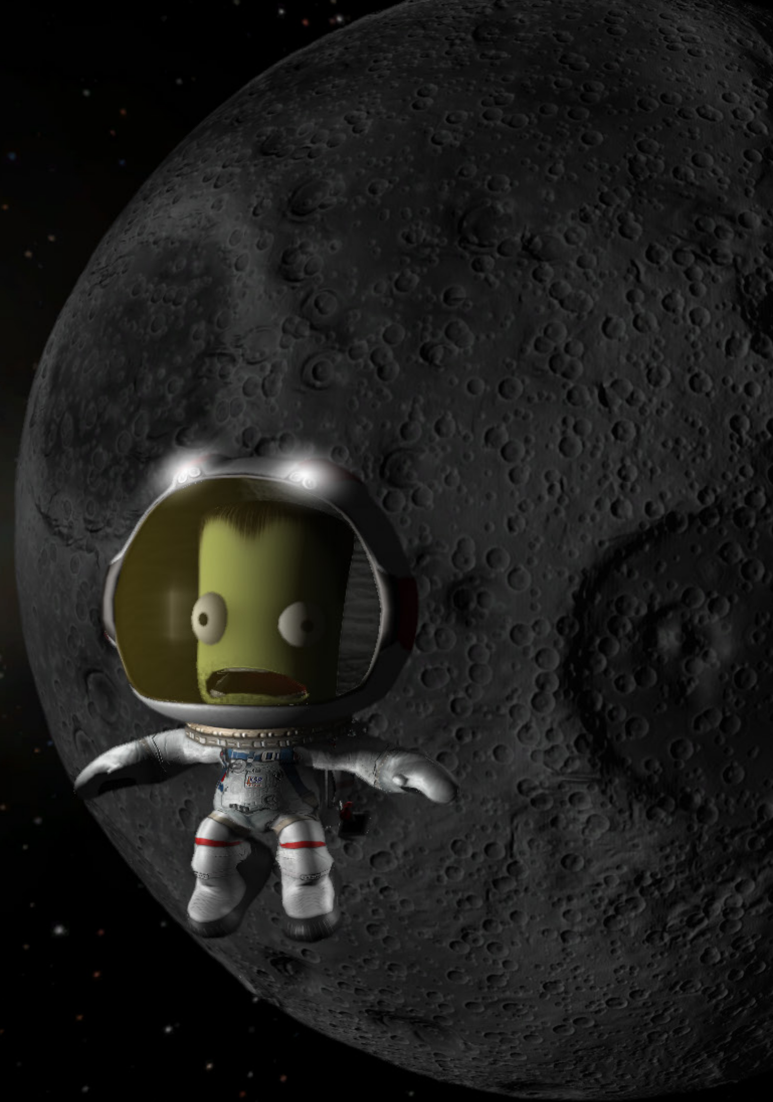
Bringing the world of astronomy to the average person has been something we've set our sights on every since the first issue of the magazine, released in January 2013.

For those who haven't been reading the magazine since Day One, we'd like to invite you to peruse the back issues. Our series of astronomy lessons to date have covered topics such as identifying the constellations, buying your first telescope, the beauty of the Earth's auroras, a must-see list of celestial objects, unpredictable nature of comets, a guide to getting started in astrophotography, and much more.

Catch up today online or download the issue as a PDF from RocketSTEM.org, or purchase a printed copy from Blurb.com.

Kerbal Space Program:

Bringing rocket science to games



Article by
Sherry Valare
and
Brenden Clark
Images by
Squad, Monkey Squad S.A de C.V.

***Bob,** that Despicable Me Minion mixed with a Martian in the photo, floats at the boundary of space, high above planet Kerbin. The space ship he was in, falls back to the planet below him. Bob ponders how he got in such a predicament, floating in space with no way home. The answer: he trusted me. Turns out, I'm a bad rocket scientist.*

But don't worry about Bob, he'll be fine. These guys are indestructible and I've got a mission on the way to retrieve the little guy already, assuming that one doesn't fail too.

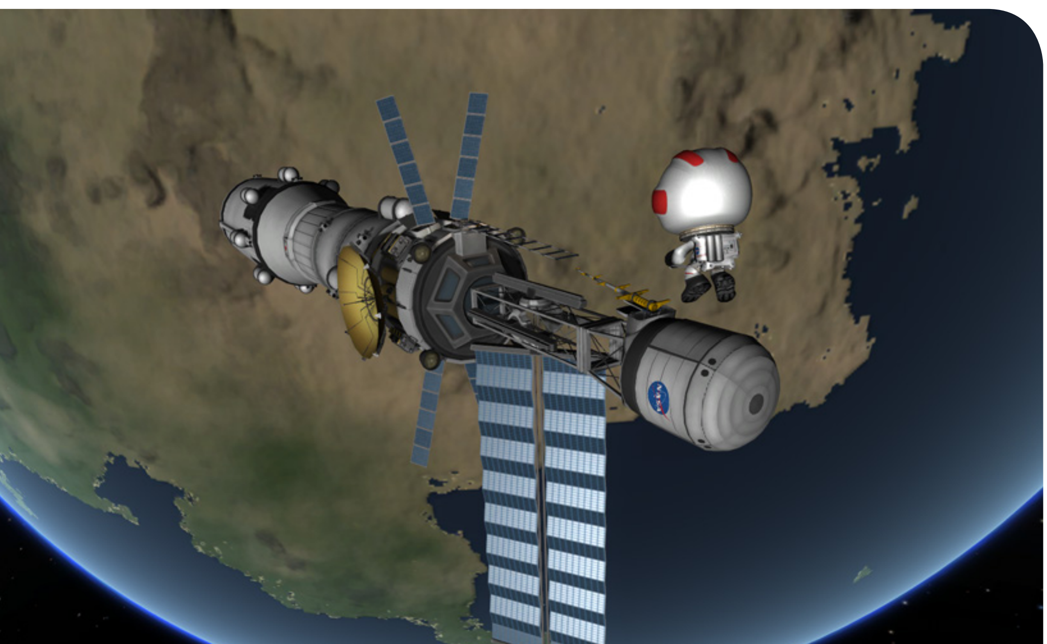
Welcome to the game Kerbal Space Program where you get to run your own space agency and decide everything from mission parameters to the design of the ships. It's as much fun to fail as it is to succeed.

Kerbal Space Program gives you an inside view on what it is like to build and fly your own rockets. It is similar to Sim City, but with rockets, space, and everything included. It is a virtual space race at your fingertips.

"Mission Control, we have a problem."

For Kerbal's creator, Felipe Falanghe - the game's idea was born out of a simple pitch to create a simple 2D game that would launch a spacecraft as high as possible to rack up points and beat high scores. The project started out small, but as any great project starts, the idea was so solid that its future was limitless. The game evolved to something bigger, with players creating mods of their own. As it became more fun and accessible for all, in 2011 Squad, the company behind it, released the game to the public.

Loosely, the goal of the game is for players to build rockets and space planes with the supplies provided so that they can explore space after successfully getting their rocket to launch off the home planet. The level of difficulty involved in these missions is determined by the player and can range from very simple to extremely difficult.



In Kerbal Space Program, your home planet is called Kerbin, and there are two moons in orbit.

The game puts your brain to the test with a steep learning curve and a variety of things you will need to keep an eye on as the administrator of your own space squad. First you need the basics: launch a rocket. Then try getting one to space without blowing up. Then try to get to the Kerbal moon and so on. Each stage adds difficulty, but also begs for creativity and innovation. A person with zero engineering experience might have an out-of-the-box design that might actually work and could change the future of rocket engineering.

The idea is that any person can play the game and find their place within all the features it has to offer. Failures and successes are even equally rewarding, sometimes.

The idea for this game has gestated since Falanghe was an imaginative teen, launching toy soldiers with spare parts and fireworks.

"The most successful design we had was a two-stage rocket that actually ignited the second stage. It was glorious", Falanghe told Andrew Groen during an interview.

Who hasn't tried to launch an Army Man with a bottle rocket, hoping to see the parachute deploy as it floats back to earth, assuming it didn't blow up and that it even made it off the ground? Flange had a dream to launch his little tin men to space. Well, that didn't work out too well at the time. But the idea stayed with him.

That dream, the fun of trying to achieve something big with so little, never getting discouraged, but simply asking why drove Falanghe. If it didn't work, why? Try to solve one problem at a time and eventually something will work. Then try to go bigger. That is the heart behind this game, and part of the credit needs to go to the company Falanghe works for. His dream remained nothing more than a dream until Squad launched a new campaign of their own. "Make your dream come true" was a program for it's employees where they could present any idea they had to the company and if the bosses liked it, they'd come on board and help to realize that dream if possible.

Remember, Squad was a marketing company. They have no experience in the world of video games. So to take on something so out of their field was ambitious, scary and most of all brave. All great things start with an idea. You have a great idea then 99% of the work is done. Squad knew they would be learning as they went, but nurturing its employees and good ideas was worth it.

Falanghe's pitch started out simple. "The first idea I pitched was actually 2D…. it could have been done in Flash. Basically you built a space craft, and tried to launch it as high as it would go… and that was basically it. It was kind of like a high score game."

But with great ideas, it started becoming grander in scope. Iteration after iteration, the game went from just launching a rocket, to recovering the rocket, to full on space flight and galactic exploration. And isn't that how all real space programs started?

Kerbal has a hugely active fan base. During its beginning stages, it rapidly gained a dedicated fan base that seemed to turn an eye to the parts of the game that were unfinished. Once it was released on Steam - a PC games platform - during the spring of 2013, it grew to be one of the top 5 best selling titles on the "early access" part of the site, which also earned it a new influx of players. The game is a work in progress with regular updates being released by Squad as well as the hundreds of ever hanging mods and additions available from the player community.

The game has an endearing and jovial touch to it. The workers in the space programs are actually little green characters called Kerbals. They operate the Kerbal Space Center (KSC), located on Kerbin - the world they live in. They write in English, but have their own language (a backwards Spanish known as "lonapsE"), that game players get to hear them speak when they are in the Astronaut Complex, in trailers for the game, or at the end credits theme.

Everything about the Kerbals seems to be "Kerbalized" to really give the little green guys their own unique character description. Aside from a select number of Kerbals that are pre-named, the rest of the species is named using "Kerman" as the last name, and a first name built out of a mixture of phonetic syllables or words chosen from a list of supplied names to choose from. The Kerbal species is even called "Kerbalkind".

For the Kerbals that are astronauts manning the vehicles players launch, a casual fan-made name (though not an official dedication by Squad) was created - Kerbonaut. The Kerbonauts have randomized traits, and are the only characters in the game that can be controlled externally by players. Any Kerbonauts employed by the Astronaut Complex are listed, along with new Kerbonaut hirings.

When it comes to game play, whereas launching a rocket for NASA requires precise calculations and restrictive physics, Kerbal has a slightly easier learning curve. Your rocket needs to make sense, and the construction needs to be of quality.

Fuel-efficiency, wind resistance, and thrust balance are all things that need to be taken into account. It's just complex enough to engage the player mentally, and just simple enough that a single person could design a great rocket that doesn't require a team of mathematicians and engineers.

The physics of Kerbal Space Program aren't anywhere near as unforgiving and restrictive as NASA has to deal with in real life, but your rocket still needs to be logical and well-constructed.

There's also a thriving mod scene that's constantly creating new devices and toys for players to tool around with. Any planet or moon can be reached with the stock parts, however, the modding community has helped to make some missions easier. Some parts even have built-in telemetry tools that can automatically fire your engines for the proper amount of time and put you on the perfect heading.

"I've actually tried to land on Duna using the sky-crane method and I have killed many Kerbals along the way," said Douglas Ellison, a visualization producer at NASA's Jet Propulsion Laboratory. He's one of the people who helps make JPL's scientifically exact digital recreations of NASA missions like

Conduct your own Apollo mission in KSP by launching a rocket to the moons Mun or Minmus.

the Curiosity Mars Landing.

Duna is the equivalent of Mars in the Kerbal universe, and Ellison worked to perfectly recreate the landing of NASA's Curiosity rover on Mars which used the sky-crane landing method. A small rocket carrying the rover parachutes down to the Martian surface, then fires rockets to hover in mid-air before lowering the rover the rest of the way to the surface on a cable. To the average person, this may seem like a complicated mission to take on, but for someone that works for NASA and is constantly exposed to these concepts, the fact that above-average challenges can be carried out, is what makes the game so interesting.

It's just complex enough to engage the player mentally, and just simple enough that a single person could design a great rocket that doesn't require a team of mathematicians and engineers.

"It's why racing drivers like racing games - no real responsibility. Time to go a little crazy. Some of the engineering principles are very sound within KSP, but you can go just a little bit crazy. Everyone who works in and around the fields of science and engineering has a thousand crazy ideas they've thought of, but would never try in real life. KSP is a place where maybe Kerbal's unique way, you can give them a try."

From an educational standpoint, Kerbal can give players a pretty realistic idea of what it really takes to build and launch a rocket and the science behind it. The game also helps players gain a whole new vocabulary when they are consistently exposed to words such as perigee, azimuth, and retrograde.

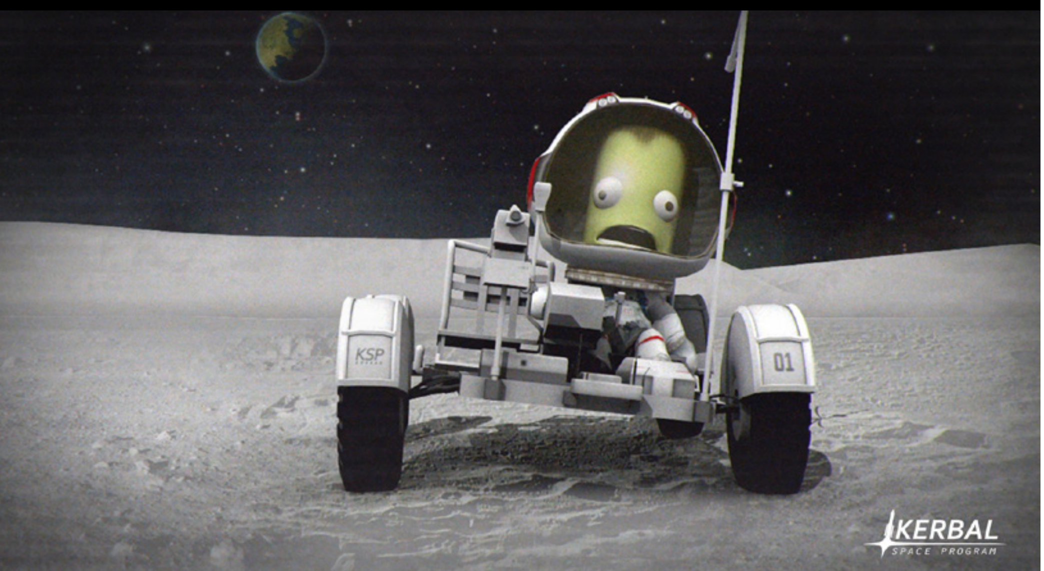
NASA even partnered with Squad

Squad, the creators of KSP, and NASA partnered to bring the Asteroid Redirect Mission into the game.

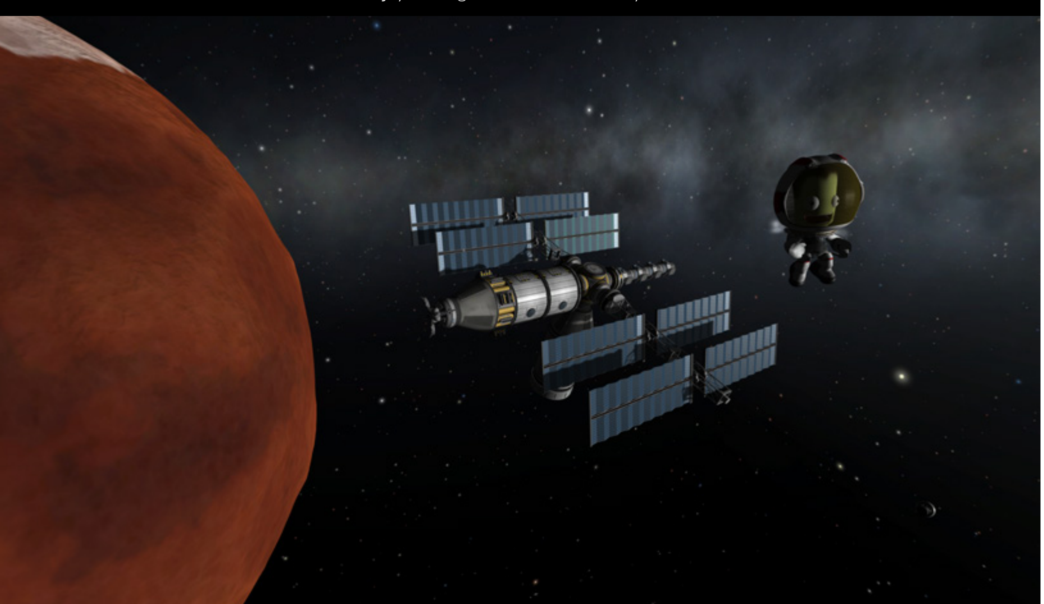
Jebediah, Bob, Bill, and Valentina are the Original Four astronauts in Kerbal, but you can create your own too.

Rocket science and fun may not be words you often hear together, but KSP makes it so.

Take a break from the rocket science and conduct your own spacewalk.



Like Earth's astronauts, Kerbals enjoy driving around in their shiny new lunar rover.



Beat NASA to the punch and land a Kerbal on Duna, the game's equivalent of Mars.

in 2013 to incorporate the Asteroid Redirect Mission into Kerbal. In real-life, this type of mission is the first of its kind. It's purpose will be to identify, capture, and redirect a near-Earth asteroid to a stable orbit around the moon, making it more accessible for astronauts to explore it and return samples. It is part of a plan NASA created to advance new technologies and spaceflight experience necessary to pave the way for a human exploration on Mars. How does that translate into the world of Kerbal? Players are able to use true-to-life, NASA approved rocket parts. It allows players to work on capturing an asteroid or changing its trajectory to prevent it from coming in contact with planet Kerbin.

WIth realistic missions and such a broad array of knowledge players have to gain from Kerbal, it may end up playing a large role in the ignition of a passion for many people that otherwise would have turned a blind eye to STEM fields. In a time where too many people think that NASA operations ended with the termination of the shuttle program, Kerbal helps to spread the word that space exploration is still a booming field. It demonstrates that concepts of rocket science and space travel that many think they are not capable of understanding, are actually attainable. WIth a little work, dedication, and little green" Kerbonauts" to keep them company in their virtual adventures, a new generation of rocketry and space lovers may be an accidental product of Felipe Falanghe's dream.

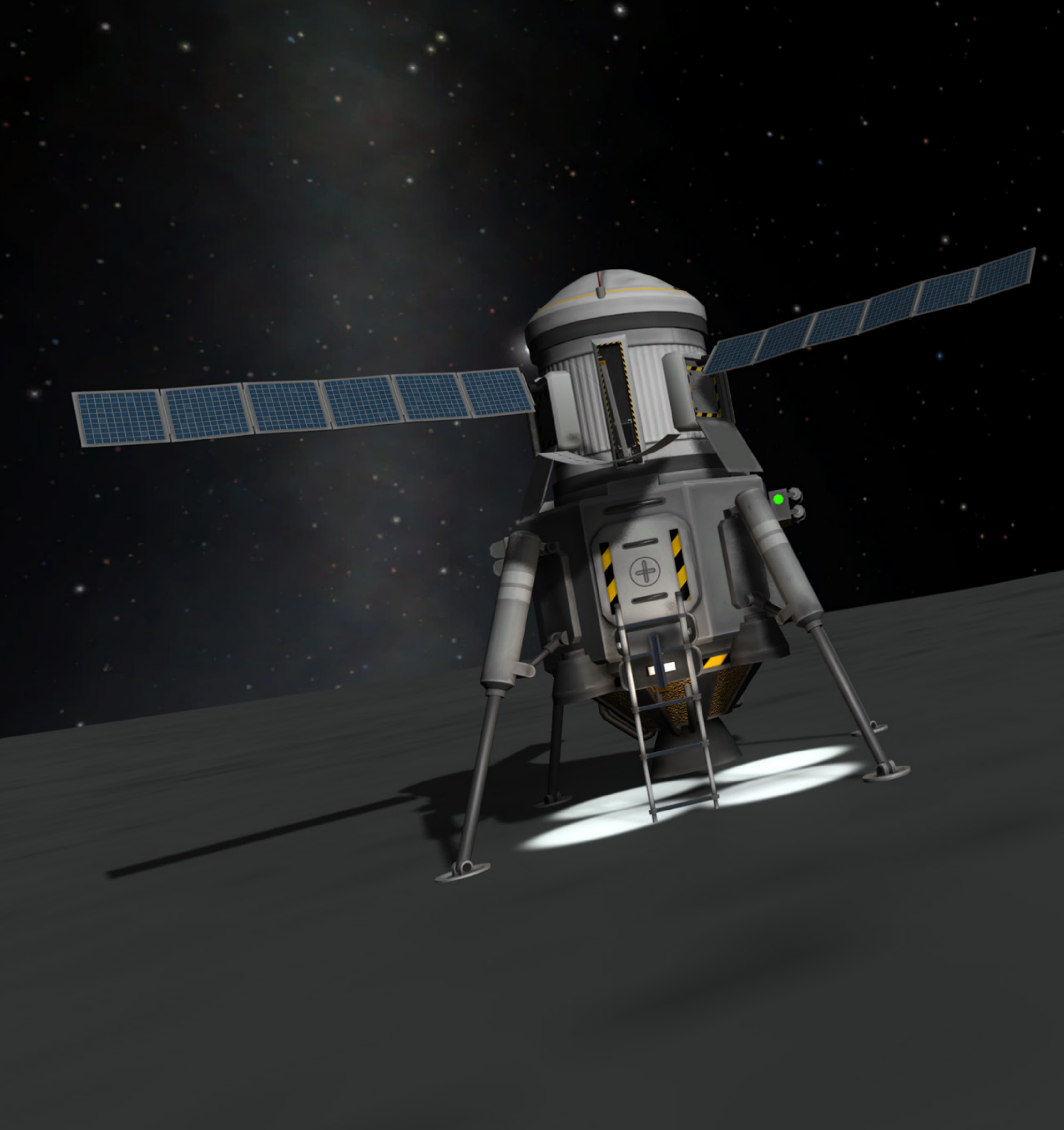
Oh and Bob, my stranded Kerbonaut, he's going to have to wait a little longer. Apparently ice-cream cone shaped rockets aren't a good idea. Hope he has something to pass the time. This might take a while.

Please visit www.rocketstem.org for more information about Kerbal Space Program, including video tutorials and online discussion forums for this popular educational game.

Author Andrew Groen also contributed to this article. He is presently writing a book titled 'Empires of Eve', a history of the great empires of the Eve Online massive multiplayer online game.

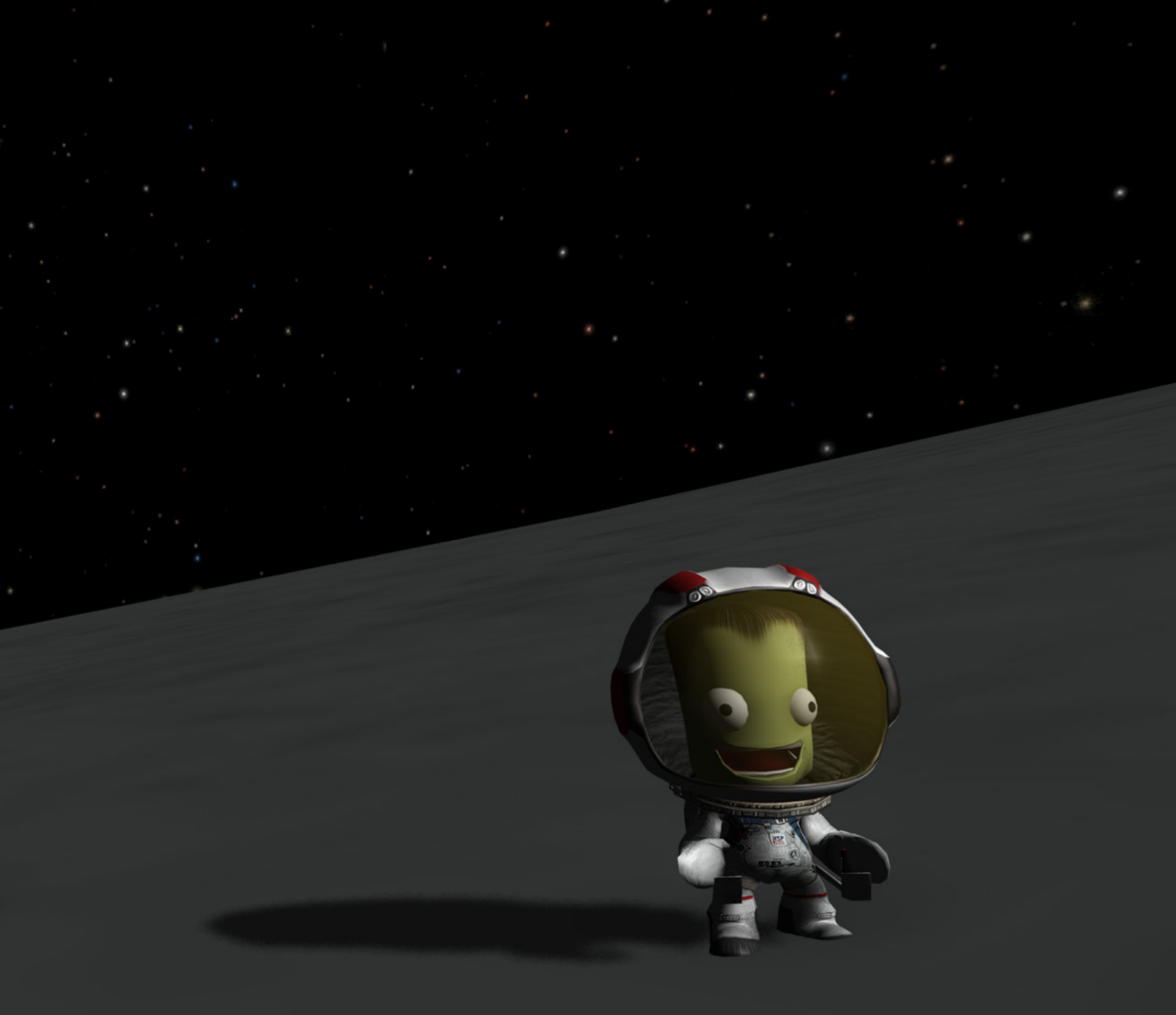
"Shoot for the moon and if you miss you will still be among the stars."

– Les Brown



“The sky is the limit only for those who aren’t afraid to fly!”

– Bob Bello

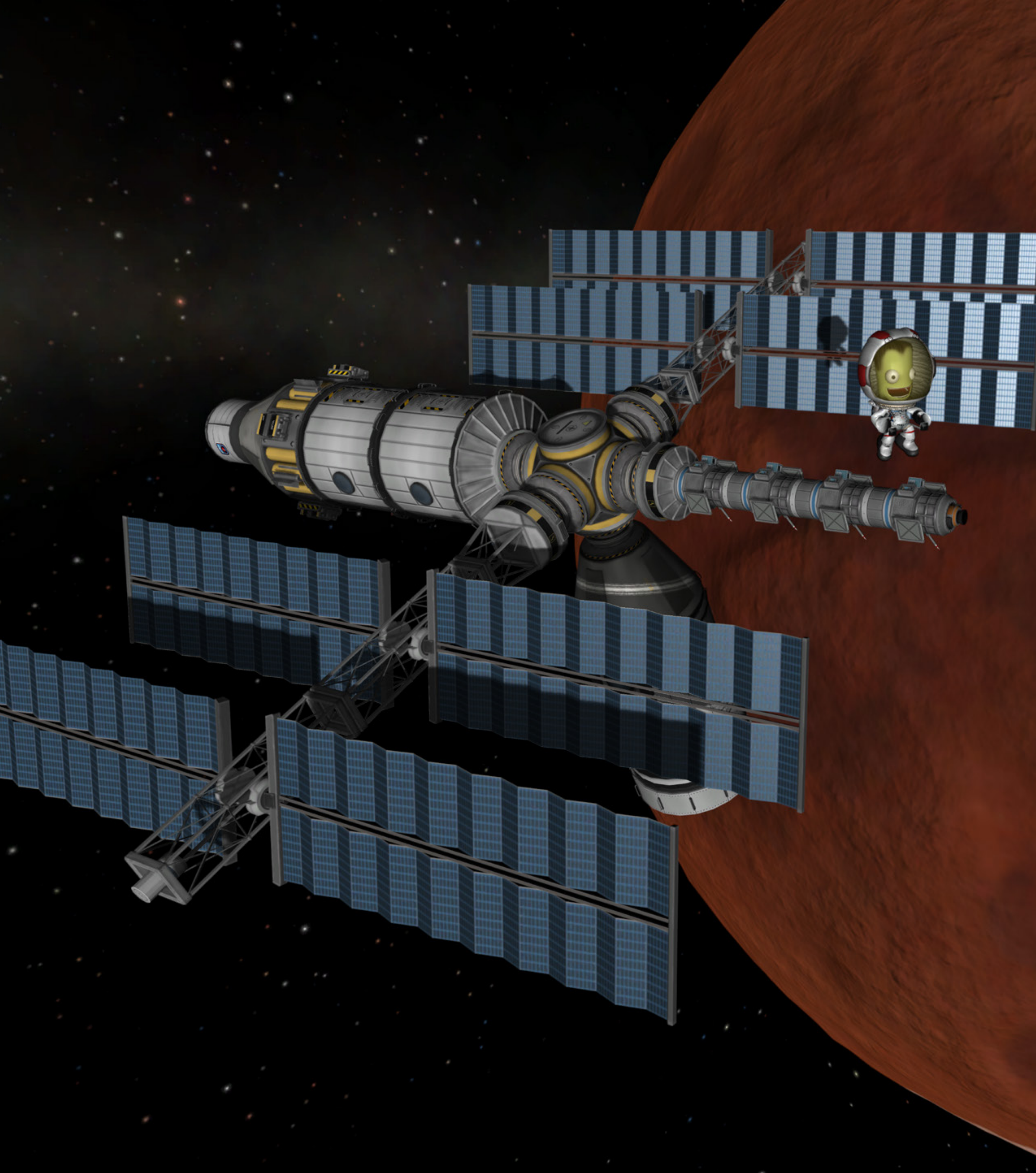


“The Moon is the first milestone on the road to the stars.”

– Arthur C. Clarke

"Mars is there, waiting to be reached."

– Buzz Aldrin



"I'm moving to Mars next week, so if you have any boxes..."

– Comedian Steven Wright

"I'M TIRED OF DRIVING AROUND THE BLOCK, BOLDLY GOING WHERE HUNDREDS HAVE GONE BEFORE IN ORBIT AROUND EARTH - GIVE ME A PLACE TO GO AND I'LL GO."

– Neil deGrasse Tyson

"I would like to die on Mars. Just not on impact."

– Elon Musk

when good rockets GO BAD

The ORB-3 Antares rocket explodes.
Credit: Ken Christison

Seconds after liftoff, the ORB-3 Antares rocket fell near the launch pad due to an apparent failure in the turbopump supplying fuel to one of the two first-stage engines. Range Safety Officers engaged the Flight Termination System to stop the remaining engine. Credit: Elliot Severn

Behind the scenes of launch control

By Tony Rice

Space flight is dangerous and not just for the astronauts. Over the hundred plus years of rocket technology and space flight growth, many have died just working on rockets or even testing them, from engineers to flight pad crew to even spectators. Progress comes with a price and with that, measures have been taken and improved over the years to try and prevent such events from happening again.

With all the advancements we've made, launching rockets is still a risky business. We were reminded of this on Oct. 28, 2014 when Orbital Science's third resupply flight to the International Space Station came to a fiery end moments after liftoff. The first fifteen seconds of the launch was uneventful before one of the two Aerojet Rocketdyne AJ26 engines in the Antares rocket's first stage failed, robbing the thirteen story tall Antares rocket of the thrust needed to overcome Earth's gravity. Early analysis of telemetry points to a failure in the turbopump providing fuel to the engine according to a statement released by Orbital days after the accident.

Along with the Antares rocket, a Cygnus spacecraft carrying 2,215 kg (4,883 lbs) of cargo for the astronauts aboard the ISS was lost. This included crew supplies (food and clothing), another third included spare parts for equipment aboard the station, and the remainder was science experiments.

Among those experiments were some created by students from around the United States and Canada participating in the Student Spaceflight Experiments Program (SSEP). These fourth graders though undergraduate students were studying everything from creating soil for growing food in space to muscle development in microgravity. That's the bad news.

The good news is that only property was damaged or lost. No one was injured because the Range Safety System and the people who run it did their job.

Each launch site has a range safety system designed to protect people and property both near the site and under the path the rocket overflies known as downrange.

Launches from the Wallops Flight Facility in Virginia are monitored from the launch site itself as well as another site on North Carolina's Outer Banks not far from where the Wright Brothers first took flight over 100 years ago. That second view of the rocket's path allows controllers to better monitor the vehicle without interference from the rocket's plume.

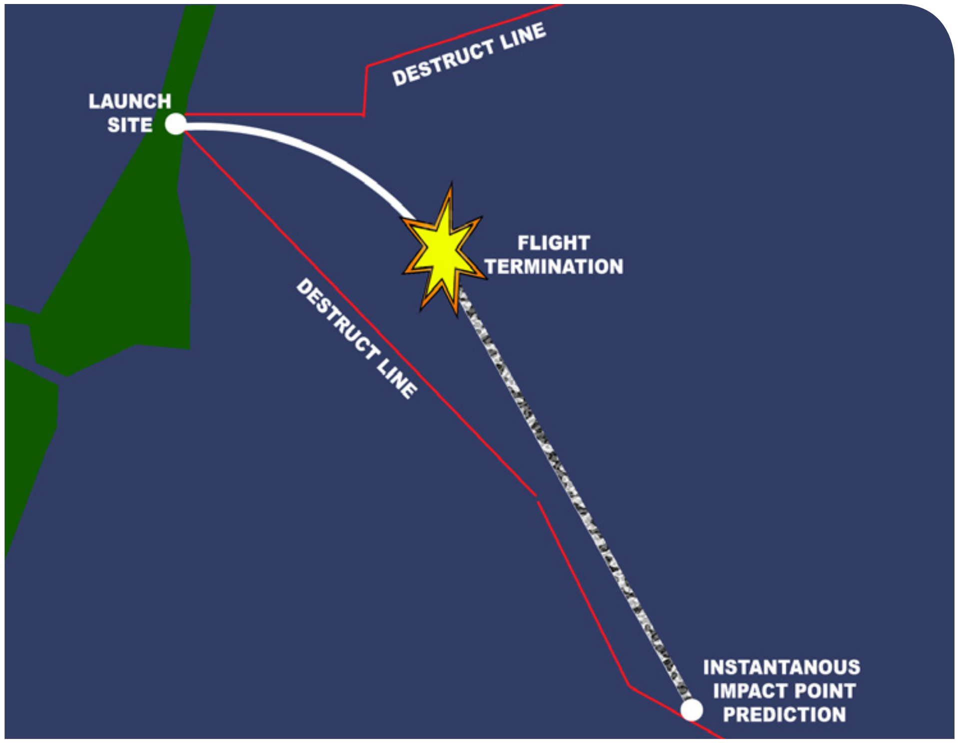
As the flight continues, tracking stations further downrange in Bermuda or the Bahamas take over providing a continuous view as the rocket heads to orbit.

Spacecraft and the rockets that carry them are relatively fragile. Overcoming Earth's gravity isn't easy. About 90% of a rocket's weight on the pad is highly explosive fuel. Should a flight go wrong, Range Safety Officers have a very powerful tool available to help protect people and property on the ground: flight termination. Also known as self-destruct, the Flight Termination System

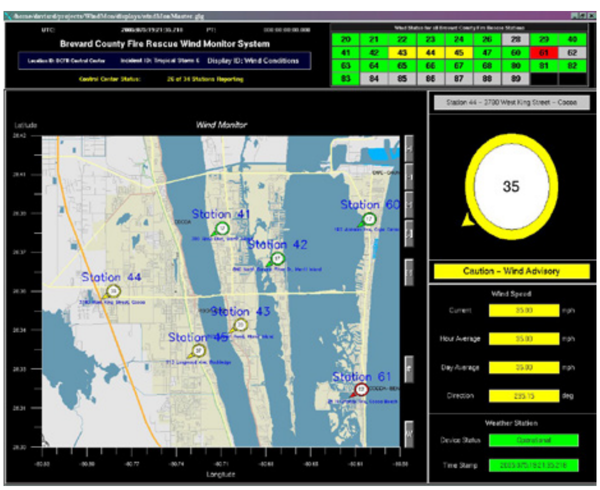
(FTS) is to make the path of an errant rocket more predictable by ending thrust from the engines immediately. This is the first line of defense against a failing vehicle and is one of the most highly reliable systems involved in the launch.

This is done by strategically placed linear-shaped charges which release a tremendous amount of very focused force. These charges can rip open an engine or fuel tank like a zipper. Remaining fuel either dissipates into the atmosphere or explodes destroying the rest of the vehicle. It's a sad way to see a highly anticipated launch end, but at least the team knows the debris can land safely inside a predefined zone.

The first few seconds of the flight are critical and where most problems occur. This is also the most difficult to track electronically. Since the earliest days of rocketry, liftoff has been observed through a vertical wire sky screen developed by James Van Allen in his work ensuring tests of the V2 and Aerobee rockets could be done safely. A long rectangular frame with 2 or more wires provides a visual reference for the rocket's path off the pad. Should the Range Safety Office see the rocket touch either wire during liftoff, the command to terminate flight is given.



As a rocket flies, its instantaneous impact point (IPP), or point where debris would land should the flight be terminated, is constantly updated. If the IPP strays beyond predetermined destruct lines, the flight is terminated ensuring debris does not land on populated areas. Credit: USAF/Rice



Before making the go-nogo decision wind conditions are evaluated not just for how they will affect the vehicle's flight but how debris might spread should that flight be terminated. Credit: NASA/CCT Corp

Once the vehicle is safely off the pad and enters the downrange portion of its flight, all flight termination decisions are based on maps prepared far in advance of the launch day. A new map is drawn up for each launch based on the type of rocket, its engines, fuel and payload. This information helps determine where destruction lines radiating out from the launch site are drawn.

Before launch day this information is used to create Notices to Airman (NOTAMs) and Notices to Mariners (NOTMARs) about areas to avoid around launch time. On launch day the United States Coast Guard supports NASA in launches from Wallops Island Virginia, Cape Canaveral Florida and Vandenberg Air Force Base, California in enforcing these avoidance areas. Launches have been postponed or even scrubbed when a small boat ventures into these areas covering many square miles. These represent not just the area where a rocket stage is planed to fall back to Earth but also where debris could fall.

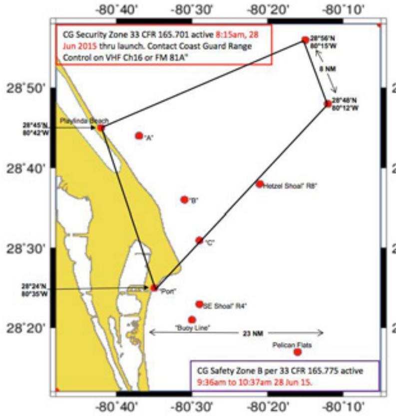
The data gathering isn't through though. Monitoring weather conditions, especially wind continues up until the launch. While weather conditions near the pad may be perfect, high winds elsewhere in the area or downrange may cause Range Safety to deny permission to launch. This ensures the maps remain reliable.

Throughout the launch, Range Safety officers track the vehicle's position and instantaneous impact point (IPP); an unpowered, ballistic path where debris is predicted to land if the rocket is destroyed at that moment. If the rocket goes off course and its IPP reaches a destruction line, the flight is terminated. This ensures debris lands within a safe zone while giving the rocket every chance to straighten up and flight right either through-automated systems or commands from the ground.

Six months later a Progress resupply spacecraft launched from the Baikonur Cosmodrome in Kazakhstan failed when controllers in Russia lost communication and the capsule tumbled out of control before reentering Earth's atmosphere 11 days later. In June 2015, SpaceX experienced their first launch failure after 18 successful ones. This was particularly difficult for a group of high school students from Palmetto Scholars Academy in North Charleston, South

Carolina. After losing their experiment in the Antares failure in October, they again watched their work destroyed aboard the SpaceX Dragon capsule.

Despite the apparent break up of the rocket 159 seconds after launch, flight termination signals were sent 70 seconds later to ensure any remaining components would not endanger anyone.



The FAA's NOTMAR map (top) and the NOTAM map (bottom) issued before the SpaceX CRS-7 launch.

"45th Space Wing Mission Flight Control Officers sent command destruct functions in accordance with Air Force policy and procedures to ensure public safety," the Air Force said in a statement. The action may have also help disperse rocket fuel harmlessly in the atmosphere making the search for debris safer.

When watching in person, from near the launch site or on TV, hearing that launch has been scrubbed because the "range is red" is frustrating. But know that this helps keep everyone on the ground out of harm's way so that should something go wrong after liftoff, the Range Safety Officers can terminate that flight safely.

Learn more about the history of keeping the Eastern Test Range safe in an Air Force film at http://goo.gl/TszjkD.

ISS suffers another loss of resupply cargo:

Falcon 9 ruptures during ascent


The SpaceX Falcon 9 rocket carrying the Dragon capsule on the CRS-7 resupply mission to the International Space Station suffered a failure of the second stage and disintegrated seconds after passing through maximum aerodynamic pressure. The rocket and cargo are presumed to be a total loss. Credit: Alan Waters/AmericaSpace

By Chase Clark

After a string of 18 successful launches to begin its pedigree, a Falcon 9 rocket manufactured by SpaceX suffered a catastrophic failure during its ascent to orbit on Sunday, June 28.

The Falcon 9 rocket was attempting to loft the Dragon capsule and service trunk on the CRS-7 resupply mission to the International Space Station. The rocket had passed through the area of maximum aerodynamic pressure (max Q) and was within 20 seconds of burnout of the first-stage Merlin engines, when the rocket disintegrated at an altitude of approximately 20 miles just 139 seconds after launch. The remaining pieces of the rocket fell harmlessly into the Atlantic Ocean off the Florida coastline.

While the exact cause of the rocket's demise is stil unknown, SpaceX founder Elon Musk tweeted on June 28 that there had been an overpressure event in the liquid oxygen fuel tank of the second stage of the rocket, and that downlinked data streamed from the rocket during the ascent indicated a counterintuitive cause.

The following morning, Musk tweeted that after several thousand hours of engineering review that the cause was still unknown.

The fact that the root cause of the failure is not immediately apparent is no cause for concern. A thorough fault tree analysis may take several months or longer to complete.

SpaceX is leading the accident investigation, with assistance offered by NASA, the FAA and the U.S. Air Force.

In slow motion video of the rocket's ascent, it appears that the second stage of the rocket ruptured and disintegrated, while the Merlin engines of the first stage continued to push the rocket upward for a few seconds. Video also shows that the Dragon capsule may have separated from the upper stage and fell uncontrollably into the ocean. It has not been located and recovered, nor is it known if it is still intact.

While SpaceX had recently conducted a successful Pad Abort Test of a redesigned version of the Dragon capsule meant to carry humans to the ISS and beyond, the Dragon capsule used for the CRS-7 launch was the cargo-only version that does not have abort during ascent capability.

The Dragon capsule and service trunk was carrying more than 4,000 pounds (1,800 kg) of food, water, supplies and experiments to the space station. Included among the cargo was the first of two planned International Docking Adapters, which are necessary to facilitate the docking of future crewed commercial spacecraft to the ISS.

After the second stage separation, SpaceX had planned to make a third attempt at doing a controlled return and landing of the first stage of the rocket on a converted barge. Two previous tries had failed, but the company had appeared to be making progress between each attempt.

SpaceX hopes to develop a reusable first stage as part of its quest to reduce the cost to launch rockets.

Front and center:

Launch inferno

By Ken Kremer

NASA WALLOPS FLIGHT FACILITY, VA - All was calm, the air was crisp with hope and the skies were clear as far as the eye could see as the clock ticked down to T minus zero for the Oct. 28, 2014 blastoff of an Orbital Sciences commercial Antares rocket from NASA's Wallops Flight Facility, VA, – on a mission of critical importance, bound for the International Space Station (ISS) and stocked with science and life support supplies for the six humans living and working aboard.

Tragically it was not to be – as I reported live from the NASA Wallops press site on that fateful October day. The 133 foot tall rocket's base exploded violently and unexpectedly some 15 seconds after a beautiful evening liftoff, due to the failure of one of the refurbished AJ26 first stage "Americanized" Soviet-era engines built four decades earlier.

I watched with anticipation, just 1.8 miles away from the launch pad, camera in hand with all the other press and spectators. It seems so far away. We all wish we could be closer, UNTIL we are rocked with multiple explosions and then we wish we were even further away.

Myself and a small group of space journalists working together from Universe Today, AmericaSpace and Zero-G News had placed sound activated cameras directly at the launch pad to capture the most spectacular up-close views for what we all expected to be a "nominal" launch.

Antares first stage is powered by a pair of AJ26 engines originally manufactured some 40 years ago in the then Soviet Union and originally designated as the NK-33. Overall this was the 5th Antares launch using the AJ26 engines.

Moments after the highly anticipated and seemingly glorious liftoff, the private Antares rocket suffered a catastrophic failure and exploded into a spectacular aerial fireball over the launch pad on the doomed Antares/Cygnus/Orb-3 mission to the ISS.

Our remote cameras were placed directly adjacent to the Antares pad OA at the Mid-Atlantic Regional Spaceport (MARS) and miraculously survived the rockets destruction as it plunged to the ground very near and just north of the seaside launch pad.

All of our teams cameras and image cards were impounded by Orbital's official and independent

Orbital Sciences' Antares rocket explodes moments after blastoff from NASA's Wallops Flight Facility, VA, on the evening of Oct. 28, 2014.
Credit: Ken Kremer

Accident Investigation Board (AIB), that was assembled quickly in the aftermath of the disaster and charged with determining the root cause of the launch failure.

The photos captured on our image cards were used as evidence and scrutinized by the investigators searching for clues as to the cause. Similar NASA and Orbital Sciences photos have not been publically released. Over a month after the event, they finally released the recordings back to us allowing me to relive the events, second by second.

Orbital Sciences' technicians at work on two AJ26 first stage engines at the base of an Antares rocket at NASA Wallops. The refurbished, Soviet era NK-33 engines most likely caused the Antares rocket failure in late 2014. Credit: Ken Kremer

My remote camera images herein shows Antares terrifying descent into a hellish inferno. And one clearly shows that the south side engine nozzle was intact after the explosion. Thus it was the north side engine that blew up.

Everything appeared normal at first. But within about five seconds or so there was obviously a serious mishap as the rocket was no longer ascending. It was just frozen in time. And I was looking directly at the launch, not through the viewfinder of my cameras.

Something was noticeably amiss almost instantly as the rocket climbed only very slowly, barely clearing the tower it seemed to me. The rocket failed to emerge from the normal huge plume of smoke and ash that's purposely deflected away by the flame trench at the base of the pad.

I was totally stunned trying to comprehend what was happening because it was all so wrong. It seemed simultaneously to last for hours and mere moments.

It was absolutely nothing like the other Antares launches I've witnessed from the media site.

I knew as a scientist and journalist that I was watching a mounting disaster unfold before my eyes.

Instead of ascending on an accelerating arc, a mammoth ball of fire, smoke and ash blew up the entire sky in front of us like a scene out of hell or war. Literally a wide swath of the sky was set on fire unlike anything I've ever witnessed. Launches usually look more like a blow-torch

I prayed the rocket would emerge unscathed, but knew it wouldn't – and it didn't.

A series of irregular, ear-piercing mid-air explosions suddenly rocked the area. And it went on and on. And now there was absolutely no doubt this was an


An Antares rocket stands erect, reflecting off the calm waters the night before its first night launch from NASA's Wallops Flight Facility, VA.

Credit: Ken Kremer


I was totally stunned trying to
comprehend what was happening
because it was all so wrong.
It seemed simultaneously to last for
hours and mere moments.
Credit: Ken Kremer

An Orbital Sciences Antares rocket descended into hellish inferno after the first stage propulsion system exploded moments after liftoff from the NASA's Wallops Flight Facility along the Atlantic seaboard in Virginia. Credit: Ken Kremer

utter catastrophe.

Suddenly I felt a pressure wave followed by a noticeable heat wave passing by. At first I wasn't sure it was real or my imagination.

But talking to others, and looking later at my video I knew it was for real. The shaking video from my tripod mounted camera dramatically proved that.

Then the rocket began to fall back to Earth. Then the ground blew up as the rocket pieces hit the ground and exploded into a hail of smithereens in every direction.

I wasn't scared – but definitely stunned beyond description. I wondered for a moment if some dangerous debris was hurtling towards us. But I realized by then it was too late anyway.

By this time within moments our NASA escorts starting yelling to abandon everything in place and head immediately for the buses and evacuate the area. A ground fire was spreading, mostly to the northern portion of the pad and the expanding air borne plume also blew northwards. The ground fire was still burning over a half hour later we could see later on videos.

Thankfully, everyone got out safe and there were no injuries due to the excellent effort by our NASA escorts trained for exactly these types of unexpected circumstances.

A series of irregular, ear-piercing mid-air explosions suddenly rocked the area. And it went on and on. And now there was absolutely no doubt this was an utter catastrophe.

It's absolutely heartbreaking for everyone's painstaking efforts to get to the point of liftoff after years of effort to fulfill the critical need to resupply that station with the science equipment and experiments for which it was built. I met many excellent folks from Orbital and NASA over the years who worked so hard and put all their hopes and dreams into this launch. It's a total tragedy.

Looking at my press site and remote photographs afterwards and seeing Antares descending frame by frame

The aerial fireball that erupted from the Antares rocket seconds after blastoff could be seen for many miles. The pressure wave and heat wave from the explosion were even felt at the press site nearly two miles away from the launch pad. Credit: Ken Kremer

into a hellish inferno and being completely consumed is beyond blood curdling. It's beyond absolutely chilling. Now I know what hell is like on Earth.

Thank God no one was on board I keep thinking to this day, replaying the disaster in my mind.

The Antares disaster will have many repercussions and some ways of doing business in space may well need to be radically altered.

Antares was carrying Orbital's privately developed Cygnus pressurized cargo freighter loaded with nearly 5000 pounds (2200 kg) of science experiments, research instruments, crew provisions, spare parts, spacewalk and computer equipment and gear on a critical resupply mission dubbed Orb-3 bound for the International Space Station (ISS).

It was the heaviest cargo load yet lofted by a Cygnus. Some 800 pounds additional cargo was loaded on board compared to earlier flights. That was enabled by using the more powerful ATK CASTOR 30XL engine to power the second stage for the first time.

The astronauts and cosmonauts depend on a regular supply train from the ISS partners to kept it afloat and productive on a 24/7 basis.

The Orbital-3, or Orb-3, mission was to be the third of eight cargo resupply missions to the ISS through 2016 under the NASA Commercial Resupply Services (CRS) contract award valued at $1.9 Billion.

Orbital Sciences is under contract to deliver 20,000 kilograms of research experiments, crew provisions, spare parts and hardware for the eight ISS flights.

In early December, Orbital Sciences said that the company is seeking to quickly make up the cargo loss to NASA by announcing the selection of the venerable Atlas V rocket built by United Launch Alliance to launch Orbital's next Cygnus cargo ship to the orbital science lab.

Orbital and ULA signed a contract to launch at least one and up to two Cygnus cargo missions to the International Space Station (ISS) under NASA's Commercial Resupply Services (CRS) program.

The first Cygnus mission would liftoff sometime late in the fourth quarter of 2015 aboard an Atlas V 401 vehicle from Space Launch Complex 41 (SLC-41) at Cape Canaveral Air Force Station in Florida. I hope to be there to witness it and look forward to reporting a more uplifting story next time.

Crisis strikes Russia's space program


Soyuz TMA-12M spacecraft rollout in 2014. Credit: NASA/Joel Kowsky

By Igor Rozenberg

A series of unfortunate events happened in end of April and beginning of May that has raised a few eyebrows about the current state of affairs in Russia's space exploration program. A string of failures unfolded in the following sequence:

- On 28th of April 2015, Soyuz-2.1a Launch Vehicle with Progress M-27M cargo vehicle experienced an anomaly that occurred in the end of third stage burn; that lead to the bad separation of the payload from upper stage and left spacecraft spinning on non-nominal orbit and unable to be fully controlled;
- On 16th of May, Progress M-26M spacecraft (already docked to module Zvezda) failed to perform a nominal burn to boost ISS orbit;
- On 16th of May 2015, (few hours later) Proton-M Launch Vehicle with a commercial payload (Mexican Government MexSat-1 satellite) experienced loss of the mission due to premature shutdown of third stage propulsion system.

Progress cargo vehicle

Progress cargo vehicle is derivative of manned Soyuz spacecraft and launched atop of either Soyuz-U or Soyuz-2.1a launch vehicle.

Progress M-27M was the 123rd Progress spacecraft mission since its maiden flight in Feb 1978.

There were the following series of Progress spacecraft:

- Progress 7K-TG (11F615A15): 42 spacecrafts flown during 1978–1990 to resupply Salyut-6, Salyut-7 and Mir Orbital stations.
- Progress-M (11F615A55): 43 spacecrafts flown during 1989-2009 to resupply Mir and ISS Orbital stations.
- Progress-M1 (11F615A55): 11 spacecrafts with extra propellent in payload flown during 2000-2004 to resupply Mir (4 missions), deorbit Mir (1) mission and resupply ISS (6 missions).
- Progress-M (11F615A60): is a current series still in production since maiden flight.

In a typical mission Progress would supply ISS with dry and liquid consumables, water and propellant for the ISS Zvezda module. Progress propulsion module used to boost the orbit of the station, and after closure of ESA ATV cargo vehicle program, Progress is only remaining spacecraft with such capability.

Aftermath: On 18th of May Russian mission control was able to reboost ISS altitude by 2.8 km after firing Progress M-26M engines for 1,922 seconds. Orbit correction burn took twice longer than planned - mission controllers fired only 4 thruster of 8 according to standard operation procedures. This created optimal conditions for Soyuz TMA-15M landing on 11th of June and rendezvous with the next cargo vehicle in mid-July. Russian mission control plans to use Progress M-26M again for the next orbit reboost.

Soyuz-2.1a/Progress M-27M launch failure

By original design Soyuz-U (rocket that launches Progress spacecrafts), Soyuz-FG (man-rated rocket that launches Soyuz spacecrafts with a crew) and Soyuz-2.1a (new generation Soyuz rocket) share that same third stage (Block I). All of those launch vehicles had been designed and manufactured in Samara Rocket Space Center PROGRESS, while propulsion system for third stage (1 x RD-0110) designed by KBKhA and manufactured by VMZ (both in Voronezh).

For the last six years there were some anomalies with Block I stage:

- 21 May 2009, Soyuz-2.1a/Fregat LV, payload Meridian 2 satellite - premature shutdown of the third stage led to loss of mission (satellite was placed on non-usable orbit that had not been corrected by Fregat space tug).
- 24 Aug 2011, Soyuz-U LV, payload Progress M-12M, mission loss was caused by a blocked fuel duct, which caused the engine on Block I to shut down prematurely .

In case of Progress M-27M launch, preliminary data indicates that things went wrong just seconds before separation, apparently depressurisation of third stage oxygen and fuel tanks caused collision between stage and spacecraft, sending it uncontrolled spin to the orbit with higher apogee. Russian mission control was not able to regain control of spacecraft and it reenter Earth's atmosphere on 8th of May. The cost of the loss of the mission was valued at RUB 2.59 billion (US $50.7 million).

Implications:

- Although Progress M-27M achieved low-earth orbit, it become a second cargo vehicle (along with Progress M-12M) that was not able to complete it mission.
- Liquid propellant rocket engine RD-0110 is not a brand new engine. Since it become space worthy in 1965 and fully certified in 1967 it had been successfully flew for more than 1,500 missions on almost all modifications of Soyuz rockets (except Soyuz-2.1b and Soyuz-2.1v); Apparently there is an alarming breakdown in quality control process, however we should wait for investigation board final report that should reveal a root cause.
- All of above launch vehicles from Soyuz LV family would remain grounded pending the results of the investigation into the failure by Accident Investigation board.
- Impact on ISS operation schedule Progress M-28M return to flight mission is tentatively scheduled for 3rd of July (originally planned for August) and it would be launched on top of Soyuz-U launch vehicle.
- Impact on ISS operation schedule for manned missions - ISS mission planners delayed the Soyuz TMA-15M landing till 11th of June and Soyuz TMA-17M launch until July.
- Progress M-27M was a second spacecraft launched on top of Soyuz-2.1a launch vehicle. Further delay in certifying Soyuz-2.1a to launch cargo Progress and manned Soyuz spacecrafts should be expected (as well as subsequent delay in planned decommissioning of Soyuz-U and Soyuz-FG launch vehicles).
- Next attempt to launch cargo supply mission on top of Soyuz-2.1a LV (maiden flight of new Progress-MS spacecraft) is tentatively scheduled for this October. By original plan all of Progress-MS spacecrafts should be launched on top of Soyuz-2.1a, while Soyuz-U LV should be decommissioned.
- Human factor - based on board findings, Roscosmos would exercise an option to replace upper management of either RSC PROGRESS, KBKhA or VMZ.

Proton-M/Mex-Sat-1 launch failure

Proton-M is a major Russian Heavy-class Launch Vehicle designed and manufactured by Khrunichev Space Center (Moscow) and it is used for launching space station modules to LEO as well as commercial and government payloads to GEO. Proton and Angara-5 are only Russian HLV.

May 2015 mission (marketed by Launch Service operator ILS) intended to deliver a commercial payload MexSat-1/Centenario satellite (Mexican government's Ministry of Communications and Transportation), manufactured by Boeing Satellite Systems International (El Segundo, CA) into a geostationary orbit.

Roscosmos used Proton-M LV in operation since maiden flight in April 2001. As of May 2015 more than 100 Proton-M launches have occurred, of which 10 have failed and three of those failures were the results of problems with the Proton-M Launch Vehicle itself:

- 5 December 2010, Proton-M upper stage and payloads (3 GLONASS satellites) failed to reach orbital velocity due to overloading of the upper stage with 1.5 tonnes of liquid oxygen, which was caused by communication error between engineers from Khrunichev and Energia.
- 2 July 2013, Proton-M first stage control failure, rocket crashed near launch pad. Accident caused by angular velocity sensors wrongly installed upside down.
- 15 May 2014, Proton-M failed during the operation of its third stage (vernier engine failure due to turbo-pump pipe leak), leading to the loss of a Russian communications satellite Ekspress-AM4R.

Preliminary flight information from mission control indicates that the anomaly occurred during the operation of the third stage, approximately 490 seconds after liftoff at an altitude of 160 kilometers (100 miles). As a result both third stage and payload burned without any traces in Earth's upper atmosphere.

Proton-M third stage propulsion system consist of main propulsion engine RD-0213 and a vernier engine RD-0124. According to preliminary finding of the investigation board the fault was in the bearing of vernier engine turbo-pump. Vernier engine RD-0124 was manufactured at VMZ Plant (Voronezh).

Proton-M LV "return to flight" mission might be postponed until Russian engineers would disassemble, verify and assemble engines to verify their quality before attempting launch, such process could take few month and ILS definitely would not launch any commercial payloads.

A predecessor Proton-K launch vehicle had a healthy track record of 44 successful missions in a row, rendering claims that "rocket has a faulty design and should be immediately replaced by Angara" as quite naive and far-fetched.

International Launch Service (ILS) a commercial subsidiary of Khrunichev Space Center decided to set up an independent investigation board into Proton-M launch anomaly in parallel with Russian state-appointed Investigation Board.

Conclusion

System crisis had been identified by few brave insiders in Russian rocket and space industry at least 10 years ago, while Russian Space agency was in denial until series of mishaps that occur during last 6 years. As a result:

- Under new management - for the last three years Russian government carried out a round of reforms in space industry by consolidating all industry assets into state-owned United Rocket and Space Corporation (ORKK) and merging it with Federal Space Agency (Roscosmos).
- India decided not to cooperate with Russian Space Agency in joint Lunar lander mission, due to

constant delays in mission timeline and high accident rate.
- It is a serious blow for industry reputation, especially for commercial payloads. Russian space operators would be hit by bigger insurance premiums and most likely might lose their share of commercial launch market, that already shrunk in current political climate.
- The majority of Soyuz and Proton-M launch vehicles still grounded until investigation boards would reveal findings of accidents. This would definitely would bring a further delay for 2015 missions.
- During his speech in Russian Parliament Russian Deputy Premier D. Rogozin outlined the following major challenges for reviving once-proud space sector:
  - Obsolete and underused manufacturing capabilities.
  - Obsolete design process without modern CAD/CAM systems.
  - Corruption and bad workforce morale.
  - Low salaries prevent attracting young graduates.
  - Personnel generation gap and loss of "Know How".
  - Low productivity.

It's not first time something wrong happening during mission launches, and unfortunately not last one. Space exploration was, still and would be a hard endeavour. The very nature of current state of affairs in Russian space industry just confirming how deep is system crisis - so far Russian space program did not recover since 90s but hopefully thing would became better in the nearest future.

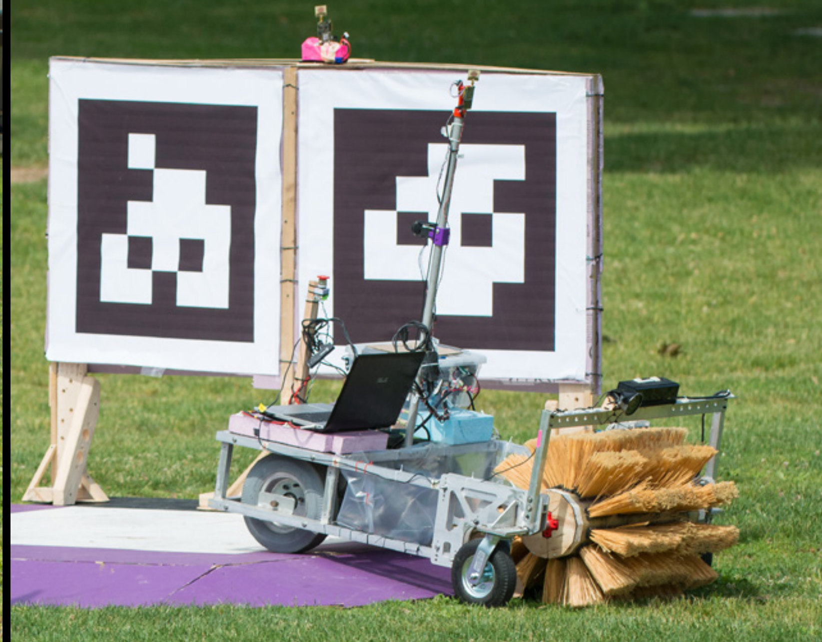
It's pity that country that pioneered the very concept of Space exploration is falling behind of US, European Union, Chinese, Indian and Japanese space missions. For the most western observers Russia is unpredictable country, so there are good chances that Russian space program achievements would became a matter of national pride.

Understanding aftermath

We have to give Russians a break because recent string of accidents reveal a strong resilience of Russian space industry. In June 2015 Russian Space agency managed to achieve the following:

- Surprising Soyuz 2.1a "return to flight" launch from Plesetsk (Kobalt-M DoD payload) on 5th of June 2015.
- Soyuz 2.1b planned launch from Plesetsk (DoD payload, possibly Persona-class satellite) on 23rd of June 2015.
- Progress M-26M spacecraft managed to successfully correct ISS orbit on multiple occasions.
- Progress M-27M Investigation board concluded that major reason for mission loss was a catastrophic event during spacecraft separation from third stage of launch vehicle. RSC Progress would perform simulation of this process and would follow up with some changes in rocket design to guarantee delivery of Progress spacecrafts on Soyuz-2.1a LV.
- Next Progress M-28M cargo mission was moved up from August to July 3, and was succesfully launched on the Soyuz-U LV (as planned).
- Proton M Investigation board concluded that premature cutoff of the third stage propulsion system happened due to turbopump design fault in vernier engine dated back to Soviet times (1985) Roscosmos decided not to extend contract of KBKhA Chif Designer Vladimir Rachuk (who created cryogenic RD-0120 engines for Soviet Energia LV - analog of American SSME) holding him personally responsible for other team design choices. Voronezh KBKhA is a rocket engine company that created and supervised production of Proton-M third stage engines.
- Roscosmos would publish Proton-M launch schedule in the beginning of July.
- Next manned mission for ISS on Soyuz-17M is planned to be launched in the end of July.

Despite recent failures of Russian rockets, the crewed version of the Soyuz has continued to be a reliable spacecraft. Here, the TMA-14M rocket launches in 2014. Credit: NASA/Aubrey Gemignani



These robots are out of this world

It may have lacked the destructive mayhem of a BattleBots competition, but the 2015 Sample Return Robot Challenge also just may hold the key in furthering our space exploration goals. Sixteen teams competed in the event held last month at the Worcester Polytechnic Institute (WPI) in Worcester, Mass. Shown here (clockwise from top left) are vehicles from the Army of Angry Robots team, the Mind and Iron team, and Team Survey. Teams were required to demonstrate autonomous robots that can locate and collect samples from a varied terrain, operating without human control. Innovations stemming from the challenge may improve NASA's capability to explore a variety of destinations in space, as well as enhance the nation's robotic technology for use in industries and applications on Earth. Credit: NASA/Joel Kowsky

Celebrating Mars New Year

The town of Mars, Pennsylvania and NASA marked the Martian New Year with a three-day celebration in the small western Pennsylvania borough.

As part of the celebration of the Red Planet's latest complete journey around the Sun, the town hosted three days of Science, Technology, Engineering, Arts and Mathematics (STEAM) activities.

Credit: NASA/Bill Ingalls