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Flight Opportunities is enabling landing technology, page 2

Masten Space Systems/Matthew Kuhns

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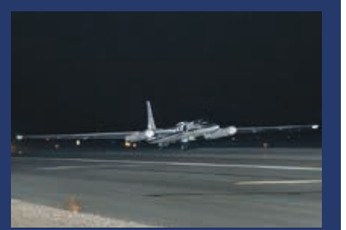
Inside



One Giant leap

Lunar lander navigation benefits from new tech

By Nicole Quenelle
Fuentek

When Apollo 11's lunar module, Eagle, landed on the Moon on July 20, 1969, it flew over an area littered with boulders before touching down at the Sea of Tranquility. The landing site had been selected based on photographs collected over two years as part of the Lunar Orbiter program.

But the "sensors" that ensured Eagle was in a safe spot before touching down were the eyes of NASA Astronaut Neil Armstrong.

"Eagle's computer didn't have a vision-aided system to navigate relative to the lunar terrain, so Armstrong was literally looking out the window to figure out where to touch down," said Matthew Fritz, principal investigator for a terrain relative navigation system being developed by Draper of Cambridge, Massachusetts. "Now, our system could become the 'eyes' for the next lunar lander module to help target the desired landing location."

That system was recently tested in the desert of Mojave, California, on a launch and landing of Masten Space Systems' Xodiac rocket (see cover).

NASA's Flight Opportunities program managed by NASA Armstrong, and the Game Changing Development program overseen by NASA's Langley Research Center in Hampton, Virginia, make the flight possible. The flight marks the first test of the system with both a descent altitude and a landing trajectory similar to what is expected on a lunar mission.

But what is terrain relative navigation? And why is it so important to NASA's Artemis program, which will return American astronauts to the Moon by 2024 and future human missions to Mars?

Without capabilities like GPS, which is designed to help people navigate on Earth, determining a lander vehicle's location is much like comparing visual cues (like road signs, important buildings, or notable landmarks) while driving a car with those cues identified on road maps.

"We have onboard satellite maps loaded onto the flight computer and a camera acts as our sensor," explained Fritz. "The camera captures images as the lander flies along a trajectory and those images are overlaid onto the preloaded satellite maps that include unique terrain features. Then by mapping the features in the live images, we're able to know where the vehicle is relative to the features on the map."

While the Apollo guidance computer was a revolutionary feat of engineering in its time, today's technology would certainly have been welcome. With the computer sounding alarms and Eagle quickly running out of fuel, Armstrong was doing his best to find a safe parking spot.

So it's no surprise that NASA and commercial partners are relying on the most advanced technology to upgrade navigation for future robotic and crewed missions to the Moon. The agency is developing a suite of precision landing technologies for possible use on future commercial lunar landers. NASA is already purchasing services for robotic Moon deliveries and is planning to ask American companies to build the next generation human landing systems.

Draper

In addition to testing its navigation system on Masten Space Systems' rocket, Draper tested part of the algorithm on an April 2019 high-altitude balloon flight in Tucson, Arizona. The Tucson flight was conducted by World View Enterprises, another Flight Opportunities flight provider.

The agency work to develop navigation sensors and related technologies falls under a larger effort now referred to as SPLICE, or the Safe and Precise Landing – Integrated Capabilities Evolution project. SPLICE has evolved from other NASA projects dating back to the early 2000s, all created to develop an integrated suite of landing and hazard avoidance capabilities for planetary missions. Contributions hail from several commercial efforts and multiple NASA centers.

Terrain relative navigation is key to the overall SPLICE effort, which also includes navigation Doppler lidar, hazard detection lidar and a high-performance onboard computer. Working together the full suite of capabilities promises to give future crewed missions much safer and precise descents to, and landings on, the lunar surface.

Getting there will be due in no small part to partnerships with commercial flight providers like Masten and others that enable test flights of the many SPLICE technologies – essentially providing a series of dress rehearsals before debut on the lunar surface. The Draper terrain relative navigation software will be ported into the SPLICE Descent and Landing Computer for an upcoming suborbital flight test onboard a Blue Origin New Shepard rocket. The flight test will mark another major step to move the technology into space flight applications, including precise lunar landings.

"These types of commercial vehicles provide us a highly valuable way to test new guidance, navigation and control technologies and reduce their flight risk before being utilized in future missions," said John M. Carson III, principal investigator for the SPLICE project at NASA's Johnson Space Center in Houston.

According to Fritz and Carson, the benefits of commercial flight testing include the ability to fly navigation sensors on different flight platforms at different

Flight Opportunities, page 8

New antenna tested in flight

Elvia Valenzuela
Armstrong Public Affairs

NASA's four aeronautics research centers collaborated to create a new lightweight antenna to boost aircraft and antenna performance.

This unique conformal antenna is designed to minimize drag to gain efficiency compared to a conventional satellite dish. Current satellite dishes are heavy and bulky and require a gimbal to maneuver and point at different satellites for communications.

This multicenter effort used aerogels to develop the conformal antenna under the Conformal Lightweight Antenna Structures for Aeronautical Communications Technologies (CLAS-ACT) activity within the Convergent Aeronautics Solutions project. NASA's Ames Research Center and Armstrong in California, Glenn Research Center in Ohio and Langley Research Center in Virginia are the agency aeronautics centers.

The CLAS-ACT team set out on a mission to design a lightweight antenna using aerogels that consist of 90% air. Aerogels are very lightweight compared to conventional antenna materials, which can result in a thin, flexible antenna with improved gain, bandwidth and efficiency.

The conformal antenna is made of 64 small antennas that combine to perform the function of one large antenna. The antenna can also maneuver the signal, minimizing interference with ground users in ways not possible with a traditional antenna.

AFRC2019-0110-14 NASA/Lauren Hughes

Armstrong staff installed a conformal antenna on the door of a T-34C aircraft to test its performance parameters. The conformal antenna was designed through a multi-center collaboration through the Conformal Lightweight Antenna Structures for Aeronautical Communications Technologies project.

AFRC2019-0102-6 NASA/Carla Thomas

The conformal antenna installed on the door of T-34C aircraft is made of aerogels which result in a thin, flexible antenna substrate with improved gain, bandwidth and efficiency.

The antenna is designed with a new commercial phased array chipset to enable a small size, low weight and power solution for beyond line-of-sight communications on small to medium scale unmanned aircraft systems (UAS). The phased array chipset reduces radio interference to ground stations to address interference concerns from UAS being integrated into the national airspace.

Antenna, page 7

Library cocoa bar

Armstrong staff customized 200 cups of cocoa and completed 185 surveys at the Armstrong Research Library event. People learned about the library's services including in-depth research assistance, data gathering, access to the library's collection of aviation, aerospace and science books and access to library collections worldwide via interlibrary loan. In addition, proctoring is offered to staff members who are taking college courses and online subscriptions are available on the Xnet. In addition, the Ken Iliff Knowledge Center was viewed as an excellent meeting room and alternate work environment in the survey.

AFRC2019-0275-14 NASA/Lauren Hughes

News at NASA

Water vapor confirmed on Europa

Forty years ago, a Voyager spacecraft snapped the first closeup images of Europa, one of Jupiter's 79 moons, revealing brownish cracks slicing the moon's icy surface. Missions to the outer solar system in the decades since have amassed enough additional information about Europa to make it a high-priority target of investigation in NASA's search for life.

What makes this moon so alluring is the possibility that it may possess all of the ingredients necessary for life. Scientists have evidence that one of these ingredients, liquid water, is present under the icy surface and may sometimes erupt into space in huge geysers. But no one has been able to confirm the presence of water in these plumes by directly measuring the water molecule itself. Now, an international research team led out of NASA's Goddard Space Flight Center in Greenbelt, Maryland, has detected the water vapor for the first time above Europa's surface. The team measured the vapor by peering at Europa through one of the world's biggest telescopes in Hawaii.

Confirming that water vapor is present above Europa helps scientists better understand the inner workings of the moon. For example, it helps support an idea, of which scientists are confident, that there's a liquid water ocean, possibly twice as big as Earth's, sloshing beneath this moon's miles-thick ice shell. See NASA.gov for additional details.

air-LUSI

New Moon-seeking sensor aims to improve Earth observations

The crew of the International Space Station snapped this image of the full Moon on April 30, 2018, as the station orbited off the coast of Newfoundland, Canada

NASA

AFRC2019-0270-409 NASA/Ken Ulbrich

***Above**, air-LUSI takes off aboard an ER-2 from Armstrong Building 703 in Palmdale for an airborne campaign to measure the Moon in November. **Bottom left**, the air-LUSI crew and ground crew at Building 703 place an air-LUSI component from the wingpod to the stand for hangar calibration.*

AFRC2019-0270-273 NASA/Ken Ulbrich

AFRC2019-0270-249 NASA/Ken Ulbrich

Ground crewman at Armstrong Building 703 in Palmdale installs a rail to support the Autonomous Robotic Telescope Mount Instrument Subsystem, which is part of air-LUSI and has a camera that scans the sky to find the Moon.

By Elizabeth Goldbaum
NASA Earth Science Technology Office

A new instrument with its eye on the Moon is taking off aboard a high-altitude NASA plane to measure the Moon's brightness and eventually help Earth observing sensors make more accurate measurements.

The airborne Lunar Spectral Irradiance Instrument (air-LUSI) is flying aboard NASA's ER-2 airplane. The ER-2 is able to soar above clouds, about 70,000 feet above ground. The flights, which occur at night to avoid scattered light from the Sun, began Nov. 13 and will wrap up Nov. 17 from Armstrong's Building 703 in Palmdale.

The NASA-funded instrument is "measuring how much sunlight is reflected by the Moon at various phases in order to accurately characterize it and expand how the Moon is used to calibrate Earth observing sensors", said Kevin Turpie, a professor at the University of Maryland, Baltimore County, leading the air-LUSI effort. Turpie and his team are funded by NASA's Earth Science Division and the National Institute of Standards and Technology (NIST).

How the Moon helps Earth sensors

Earth-observing sensors, like the Visible Infrared Imaging Radiometric Suite (VIIRS) aboard the NASA/NOAA/DOD Suomi National Polar-orbiting Partnership satellite and the NOAA-20 meteorological satellite, collect images of cloud cover, land surface cover and ocean color. While these sensors are diligently doing their jobs, they also have to brace against high-energy particles and withstand ultraviolet light, which degrade their sensors over time.

To account for any changes in sensitivity, VIIRS and other satellite instruments calibrate their sensors by looking at a known reference and comparing how the most recent look compares to previous ones. If the sensor sees the reference differently than before, it knows it needs to recalibrate or adjust its sensitivity.

Currently, many instruments carry an opaque or white material, called a diffuser, that reflects sunlight and acts as a reference for sensor calibration. However, although the Sun provides a steady output, its harsh rays degrade the diffuser over time. The Moon, on the other hand, is an ideal diffuser since its reflectance of sunlight is stable and more similar to Earth's in brightness.

Scientists have long known about the Moon's potential. "Not long after the Apollo program, a group at the U.S. Geological Survey (USGS) developed a way of characterizing the Moon so that Earth observing satellites could use it for calibration," Turpie said.

The USGS Robotic Lunar Observatory (ROLO) in Flagstaff, Arizona, measured the Moon on a monthly basis from 1995 to 2003. Tom Stone, a scientist at USGS, along with Hugh Kieffer, a former scientist with USGS, developed a ROLO-based model that has and continues to be used to help calibrate Earth observing sensors in instruments, like the Sea Viewing Wide Field-of-View Sensor, or SeaWiFS, which operated from 1997 to 2010 and measured ocean color to monitor phytoplankton. SeaWiFS looked at the Moon on a regular basis to note any changes in its instrument's sensitivity.

Although a lot of Earth observing mission calibration teams use ROLO, there can be large discrepancies in their lunar calibration data, Stone said. The hope is that air-LUSI's highly accurate measurements will characterize those discrepancies and determine if they're caused by internal biases in the ROLO model or something else. "We can't validate ROLO calibrations to any better than 5%," Stone said. "Air-LUSI can improve ROLO or determine what needs to be improved."

Air-LUSI's novel instruments are able to obtain highly accurate lunar spectral irradiance measurements that will have the lowest ever uncertainty (less than 1%), Turpie said, which establishes the Moon as an absolute calibration reference and helps remote sensing scientists determine if Earth observing sensors, like VIIRS, are recording actual changes on Earth or changes in their instruments.

Although Earth observing missions can look at the Moon at the same time and phase every month as a way to notice trends in their instruments' sensitivity, they haven't yet been able to use the Moon as an absolute calibration reference, Kurt Thome, a project scientist for Earth observing missions at NASA's Goddard Space Flight Center in Greenbelt, Maryland, said.

What does it mean to be an absolute calibration reference? If you

Air-LUSI, page 8

NASA honors Armstrong staff

NASA recognized some of Armstrong's finest staff members at a special ceremony at the center.

The awards went to 22 staff members and five project teams.

Armstrong Center Director David McBride, and special guest NASA Headquarters Chief of Staff Janet C. Karika, presented the awards.

The winning individuals and teams are listed in the 2019 NASA Honor Awards brochure designed by David Faust with images by Ken Ulbrich on the Xnet at https://afrcshare.ndc.nasa.gov/SitePages/Home.aspx

AFRC2019-0234-33 **NASA/Lauren Hughes**

Bart Henwood, center, receives the NASA Group Achievement Award on behalf of the Armstrong Aviation Safety Working Group from McBride and Karika.

AFRC2019-0234-34 **NASA/Lauren Hughes**

Kevin Weinert, center, receives the NASA Group Achievement Award for the Armstrong Acoustic Research Measurement Test Team from McBride and Karika.

AFRC2019-0234-35 **NASA/Lauren Hughes**

Chuck Rogers, center, receives the NASA Group Achievement Award for the Armstrong Orion Ascent Abort 2 Development Flight Instrumentation and Communication Team from McBride and Karika.

AFRC2019-0234-36 **NASA/Lauren Hughes**

Larry Hudson, center, receives the NASA Group Achievement Award for the Passive Aerolastic Tailored Wing Test Team from McBride and Karika.

AFRC2019-0234-37 **NASA/Lauren Hughes**

Mauricio Rivas, center, receives the NASA Group Achievement Award for the Armstrong UAS Integration into the NAS Integrated Test and Evaluation team from McBride and Karika.

A happy, howling Halloween

AFRC2019-0269-44 NASA/Lauren Hughes

First place chili winners are from left, Maria Caballero, Michael Worby, Steve Foster, Anthony Rodgers, Carol-Ann Thomas and Michael Rodriguez.

It was a scary good time at the annual Halloween chili cook-off, bake sale and costume contest at main base and Building 703 in Palmdale. The Armstrong Employee Exchange Council, volunteers and participants made it an event where $1,294 was raised. The winners:

Judges choice
First – Off the Hook Chili, the HMS Hawks
First (Building 703) – Not Kevin's Chili, Rafael Alicea Ortiz
Second – Jason's Pork-Pumpkin Chili, Jason Gonella
Third – Ghost Chili, Code 800

People's choice
First – Redemption Chili, Code 700
First – Game on Chili, Ken Norlin (Building 703)
Second – Off the Hook Chili, HMS Hawks

Costume contest
First Mini Me – Lila Ann Jones
First Individual – Pink Lady, Laurie Bearden
First Group – 60s NASA Engineers, Ops Engineering

AFRC2019-0259-33 NASA/Lauren Hughes

First place group costume contest winners are from left, Daniel Son, Mike Buttigieg, Jacob Wilson, Mirela Isic, Jacob Woods and Pat Stoliker.

AFRC2019-0269-08 NASA/Lauren Hughes

AFRC2019-0269-42 NASA/Lauren Hughes

At far left, *first place mini me costume contest winner Lila Jones, is seen with her parents Tom and Avalon Jones.* ***At left****, Pink Lady Laurie Bearden, middle, was individual category champ.*

Antenna... from page 3

The phased array demonstrated the ability to lower side lobes, or unintentional radiation from the antenna, as the conformal antenna delivers its signal to its intended target.

The project team performed flight tests with the antenna installed on the luggage door of a T-34C aircraft. A newly developed robotic antenna scanner allowed for extended preflight testing and verification. Both tests measured the antenna pattern characteristics to determine the feasibility of interference mitigation techniques. The team completed five flight tests including four antenna configurations within a variety of flight altitudes and demonstrated a reduction of side lobes.

The antenna was designed and tested in the anechoic chamber at Glenn, the on-aircraft modeling of the antenna performance happened at Langley, the preflight planning was accomplished at Ames and the integration and flight tests were performed at Armstrong.

The CLAS-ACT team has documented its research outcomes and lessons learned to support aeronautics as more companies introduce their UAS. The cross-center collaboration will continue as the team determines its next steps.

Flight Opportunities... from page 2

altitudes. While the Masten vehicle enables data collection for the descent and landing part of navigation, stratospheric balloon flights are helping the team tune the terrain relative navigation algorithm for higher altitudes when a spacecraft is approaching lunar orbit.

"By testing on different platforms and at different altitudes we're able to get the full range of the algorithm's capabilities," explained Fritz. "This helps us identify where we'll need to transition between satellite maps for different periods of the flight."

Earlier this year, Flight Opportunities facilitated a test of the high-altitude part of Draper's navigation algorithm on a balloon flight with World View Enterprises in Tucson, Arizona. The data from balloon flights combined with the research on Masten's vehicle will be used to better calibrate the navigation algorithms.

"If we didn't have these integrated field tests, a lot of new precision landing technologies might still be sitting in a lab or on paper, being deemed too risky for flight," Carson said of the benefit of commercial flight tests. "This gives us the very necessary opportunity to get the data we need, make the necessary revisions, and build insight and confidence into how these technologies will perform on a spacecraft."

Beyond test flights, SPLICE technologies are targeted for inclusion on upcoming flights to the Moon through NASA Commercial Lunar Payload Services. Other terrain relative navigation technologies developed prior to SPLICE have also made their way onto mission manifests for Mars, including the Mars 2020 lander vision system.

Following Apollo 11, Armstrong went on to note that the landing was in fact his biggest concern of the mission. "The unknowns were rampant," he said. "There were just a thousand things to worry about." New technologies promise to supply astronauts with even more precise information (and fewer concerns) to increase landing safety as they navigate to the lunar surface.

The NASA Artemis lunar exploration program includes sending a suite of new science instruments and technology demonstrations to study the Moon, landing the first woman and next man on the lunar surface by 2024, and establishing a sustained presence by 2028. The agency will leverage its Artemis experience and technologies to prepare for the next giant leap – sending astronauts to Mars.

Air-LUSI... from page 5

compare two people standing next to each other, it's easy to see which person is taller. However, if these two people are at opposite ends of the world, the only way to compare their heights would be with an absolute reference, like a ruler. Air-LUSI is aiming to make the Moon an absolute calibration reference, which means an instrument would only need to look at the Moon once to determine the instrument's absolute sensitivity, while comparing looks over time to see if the instrument is changing, Thome said.

A collaborative effort

To gather information about the Moon, air-LUSI includes three subsystems, which require expertise from multiple organizations, said Turpie. His team includes people from NIST, the USGS, the University of Guelph in Ontario, Canada and NASA.

The first component is called IRIS, short for Irradiance Instrument Subsystem, and was designed by NIST. It includes an instrument able to take precise measurements of the Moon while sitting in a temperature and pressure-controlled enclosure.

The second component is a robotic telescope mount called ARTEMIS (Autonomous Robotic Telescope Mount Instrument Subsystem) designed and built by the University of Guelph. ARTEMIS has a camera that scans the sky until it finds the Moon and directs the telescope to point at it and keep it locked in place, regardless of aircraft motion.

The final component is the High-altitude ER-2 Adaptation, or HERA. HERA includes all the connective tissue, like cables and mounting equipment, which holds the instrument together and to the plane, as well as the thermal stabilizing components. Air-LUSI is able to record data during flight and download the data from the plane to the ground.

One small step for air-LUSI, one giant leap for Earth science

In the near future, an operational weather satellite would benefit from being able to look to the Moon as an absolute calibration reference, Thome said. This includes the currently-flying Suomi National Polar-orbiting Partnership (Suomi NPP) and Joint Polar Satellite System-20 (JPSS) satellites, as well as those to come in the future from both NOAA and their international partners. Each satellite could calibrate its instruments by the Moon to compare how its sensors are holding up to the other satellites' sensors, Thome said.

NASA's upcoming Ocean Color Imager, aboard the Phytoplankton Aerosols Clouds and ocean Ecology (PACE) satellite, also intends to use the Moon for calibration, Turpie said.

"Air-LUSI's Moon measurements make it easier for people to justify using the Moon to calibrate their instruments," Thome said.

The X-Press is published the first Friday of each month for civil servants, contractors and retirees of the NASA Armstrong Flight Research Center.

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