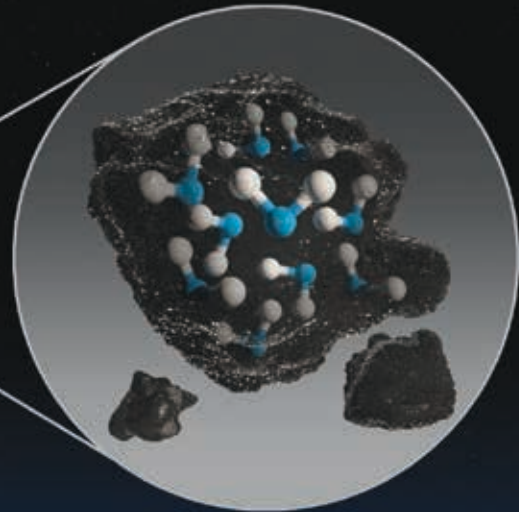
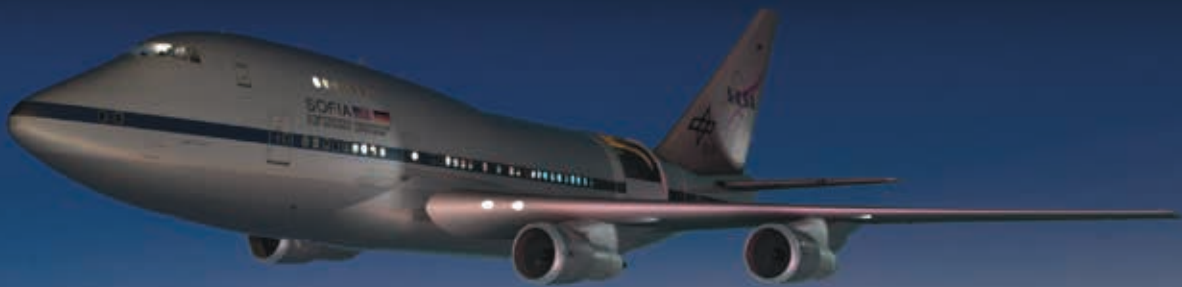




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Water on the Moon



NASA/Daniel Rutter

This illustration highlights the Moon's Clavius Crater with an illustration depicting water trapped in the lunar soil there, along with an image of NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) that found sunlit lunar water. See story on page 2. The background image accompanying the story shows the tail of SOFIA and the Moon (ED08-0067-35 by Tom Tschida).

SOFIA finds water on the Moon

By Felicia Chou

NASA Headquarters and

Alison Hawkes

NASA Ames Research Center

NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) has confirmed, for the first time, water on the sunlit surface of the Moon. This discovery indicates that water may be distributed across the lunar surface, and not limited to cold, shadowed places.

SOFIA has detected water molecules (H₂O) in Clavius Crater, one of the largest craters visible from Earth, located in the Moon's southern hemisphere. Previous observations of the Moon's surface detected some form of hydrogen, but were unable to distinguish between water and its close chemical relative, hydroxyl (OH). Data from this location reveal water in concentrations of 100 to 412 parts per million – roughly equivalent to a 12-ounce bottle of water – trapped in a cubic meter of soil spread across the lunar surface. The results are published in the latest issue of *Nature Astronomy*.

"We had indications that H₂O – the familiar water we know – might be present on the sunlit side of the Moon," said Paul Hertz, director of the Astrophysics Division in the Science Mission Directorate at NASA Headquarters in Washington. "Now we know it is there. This discovery challenges our understanding of the lunar surface and raises intriguing questions about resources relevant for deep space exploration."

As a comparison, the Sahara desert has 100 times the amount of water than what SOFIA detected in the lunar soil. Despite the small amounts, the discovery raises new questions about how water is created and

how it persists on the harsh, airless lunar surface.

Water is a precious resource in deep space and a key ingredient of life as we know it. Whether the water SOFIA found is easily accessible for use as a resource remains to be determined. Under NASA's Artemis program, the agency is eager to learn all it can about the presence of water on the Moon in advance of sending the first woman and next man to the lunar surface in 2024 and establishing a sustainable human presence there by the end of the decade.

SOFIA's results build on years of previous research examining the presence of water on the Moon. When the Apollo astronauts first returned from the Moon in 1969, it was thought to be completely dry. Orbital and impactor missions over the past 20 years, such as NASA's Lunar Crater Observation and Sensing Satellite, confirmed ice in permanently shadowed craters around the Moon's poles. Meanwhile, several spacecraft – including the Cassini mission and Deep Impact comet mission, as well as the Indian Space Research Organization Chandrayaan-1 mission – and NASA's ground-based Infrared Telescope Facility, looked broadly across the lunar surface and found evidence of hydration in sunnier regions. Yet those missions were unable to definitively distinguish the form in which it was present – either H₂O or OH.

"Prior to the SOFIA observations, we knew there was some kind of hydration," said Casey Honniball, the lead author who published the results from her graduate thesis work at the University of Hawaii at Mānoa in Honolulu. "But we didn't know how much, if any, was actually water molecules – like we drink every day – or something more like drain cleaner."

SOFIA offered a new means of

looking at the Moon. Flying at altitudes of up to 45,000 feet, this modified Boeing 747SP jetliner with a 106-inch diameter telescope reaches above 99% of the water vapor in Earth's atmosphere to get a clearer view of the infrared universe. Using its Faint Object infraRed CAmera for the SOFIA Telescope (FORCAST), SOFIA was able to pick up the specific wavelength unique to water molecules, at 6.1 microns, and discovered a relatively surprising concentration in sunny Clavius Crater.

"Without a thick atmosphere, water on the sunlit lunar surface should just be lost to space," said Honniball, who is now a postdoctoral fellow at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "Yet somehow we're seeing it. Something is generating the water, and something must be trapping it there."

Several forces could be at play in the delivery or creation of this water. Micrometeorites raining down on the lunar surface, carrying small amounts of water, could deposit the water on the lunar surface upon impact. Another possibility is there could be a two-step process whereby the Sun's solar wind delivers hydrogen to the lunar surface and causes a chemical reaction with oxygen-bearing minerals in the soil to create hydroxyl. Meanwhile, radiation from the bombardment of micrometeorites could be transforming that hydroxyl into water.

How the water then gets stored – making it possible to accumulate – also raises some intriguing questions. The water could be trapped into tiny beadlike structures in the soil that form out of the high heat created by micrometeorite impacts. Another possibility is that the water could be hidden between grains of

lunar soil and sheltered from the sunlight – potentially making it a bit more accessible than water trapped in beadlike structures.

For a mission designed to look at distant, dim objects such as black holes, star clusters, and galaxies, SOFIA's spotlight on Earth's nearest and brightest neighbor was a departure from business as usual. The telescope operators typically use a guide camera to track stars, keeping the telescope locked steadily on its observing target. But the Moon is so close and bright that it fills the guide camera's entire field of view. With no stars visible, it was unclear if the telescope could reliably track the Moon. To determine this, in August 2018, the operators decided to try a test observation.

"It was, in fact, the first time SOFIA has looked at the Moon, and we weren't even completely sure if we would get reliable data, but questions about the Moon's water compelled us to try," said Naseem Rangwala, SOFIA's project scientist at NASA's Ames Research Center in California's Silicon Valley. "It's incredible that this discovery came out of what was essentially a test, and now that we know we can do this, we're planning more flights to do more observations."

SOFIA's follow-up flights will look for water in additional sunlit locations and during different lunar phases to learn more about how the water is produced, stored, and moved across the Moon. The data will add to the work of future Moon missions, such as NASA's Volatiles Investigating Polar Exploration Rover (VIPER), to create the first water resource maps of the Moon for future human space exploration.

In the same issue of *Nature Astronomy*, scientists have published a paper using theoretical

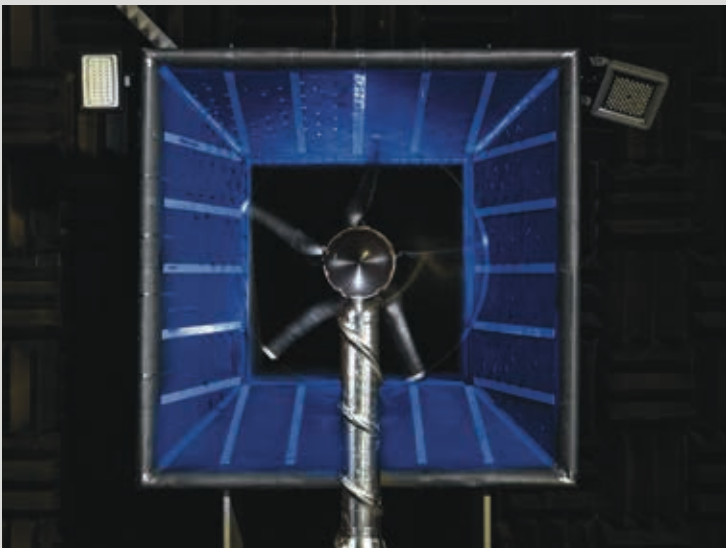
X-59 vertical tail unpacked



Lockheed Martin

The vertical tail of NASA's X-59 Quiet SuperSonic Technology airplane is unpacked from its shipping crate after delivery to Lockheed Martin's Skunk Works facility in Palmdale. Assembly is taking shape there in anticipation of the X-59's first flight sometime in mid-2022. Made of an aluminum alloy, the vertical tail's pale green color comes from a corrosion-protecting coating applied to the bare metal. The structure will be placed atop the single F414-GE-100 jet engine to form the X-59's tail and contribute to the aircraft's overall height of 14 feet. Designed to produce quiet sonic "thumps" when flying supersonic, the X-59 will be flown over select communities to measure public perception of the sound. Results will be given to regulators to use in determining new rules that could allow commercial faster-than-sound air travel over land.

X-57 prop design tested in wind tunnel



NASA

Advanced designs that will propel NASA's first all-electric X-plane, the X-57 Maxwell, to flight recently underwent wind tunnel testing at Langley Research Center. These tests, which took place in the Langley Low-Speed Aeroacoustic Wind Tunnel, were conducted to gather valuable operational and performance data for flight conditions, using two of the full-scale propeller assemblies, provided by Empirical Systems Aerospace, or ESAero, of San Luis Obispo. NASA will install 12 of these electric high-lift motors and propellers into the final configuration of X-57, called Modification IV, or Mod IV.

News at NASA

Crew-1 is a success

An international crew of astronauts headed to the International Space Station following a successful launch on the first NASA-certified commercial human spacecraft system in history. NASA's SpaceX Crew-1 mission lifted off Nov. 15 from NASA's Kennedy Space Center in Florida.

The SpaceX Falcon 9 rocket propelled the Crew Dragon spacecraft with NASA astronauts Michael Hopkins, Victor Glover, and Shannon Walker, along with Soichi Noguchi of the Japan Aerospace Exploration Agency, into orbit to begin a six-month science mission aboard the space station.

The Crew Dragon spacecraft, named Resilience, docked autonomously to the station Nov. 16.

The Crew-1 mission is the first of six crewed missions NASA and SpaceX will fly as part of the agency's Commercial Crew Program. This mission has several firsts including:

- The first flight of the NASA-certified commercial system designed for crew transportation, which moves the system from development into regular flights;
- The first international crew of four to launch on an American commercial spacecraft;
- The first time the space station's long duration expedition crew size increased from six to seven crew members, which will add to crew time for research; and
- The first time the Federal Aviation Administration has licensed a human orbital spaceflight launch.

Derek Abramson and Robert Jensen install one of two wings on the Hybrid Quadrotor 90C (HQ-90) at NASA Armstrong's Dale Reed Subscale Flight Research Lab Oct. 1. This vertical lift and transition remotely piloted aircraft arrived in pieces packed in crates for the Resilient Autonomy project to test software in flight



AFRC2020-0108-24

NASA/Ken Ulbrich

Autonomous systems

Project aims to avoid aircraft collisions, save lives

By Teresa Whiting
Armstrong Public Affairs

Autonomous aircraft systems have the potential to save lives, and NASA Armstrong's Resilient Autonomy project is at the forefront of development. These advanced software systems are preventing air-to-ground collisions in piloted aircraft, and the project is now focusing on developments to prevent aircraft from colliding with other aircraft in the air.

The project is a joint collaboration with the Federal Aviation Administration (FAA) and the Office of the Secretary of Defense with numerous Department of Defense services and commands to create new autonomous technology and inform FAA certification guidelines. The task is to test



NASA/Mark Skoog

This screenshot is from the Common Integration Tool (CIT) simulator showing the Expandable Variable Autonomy Architecture (EVAA) system. EVAA has the potential to be retrofitted for use on general aviation aircraft, or for future autonomous aircraft. The screen shows a Cirrus SR22 in the Sierra Nevada mountains evaluating the ground collision avoidance system. The display in the upper left indicates that the terrain cannot be cleared to the right or straight ahead, but turning to the left will clear the terrain.

the maturity of technology and inform airworthiness requirements to enable future autonomy, such as link-less operations in an unpiloted aircraft, while at the same time providing enhanced automatic safety to modern piloted aircraft. The system that spans this wide range of autonomy is the Expandable Variable Autonomy Architecture (EVAA).

Mark Skoog, NASA Armstrong principal investigator for autonomy, is leading the project along with project manager Kia Miller and project chief engineer Nelson Brown. Skoog comes from more than 35 years of experience with autonomous systems including the F-16 Automatic Ground Collision Avoidance System (Auto GCAS), which has saved the lives of 10 F-16 pilots,

and one more pending review. The Auto GCAS system takes control of an aircraft from the pilot at the last possible moment to avoid an imminent ground collision. For this project, the team improved the algorithms of the F-16 GCAS and ACAS systems and rebranded to indicate an improved functionality.

The EVAA software prioritizes human safety over preventing damage to property, and preventing damage is prioritized over the completion of the mission by following a set of programmed rules of behavior. These rules of behavior allow EVAA to better manage the mission intent of the flight while always maneuvering within the acceptable performance limits of the aircraft, much like how a pilot manages a safe flight. EVAA is primarily intended to be used on unpowered vehicles, and in some circumstances, may allow damage or destruction of the UAS to avoid piloted aircraft. The process involves having separate computerized monitors, each focused on one aspect of safety.

“GCAS and ACAS are each separate monitors within EVAA and we had to refashion each of these algorithms so they would be applicable to aircraft other than the F-16,” Skoog said. “We channel these monitors through a central function we call the Moral Compass, which gives control of the aircraft to the highest consequence task. Consequence is dictated by a set of rules of behavior, which dictate when safety should outweigh the mission and when vehicle safety should be compromised to protect human life.”

EVAA is developing in stages, where the software will fly in various maneuvers in the aircraft simulator. The process began with the read-only phase, or build one, where the sensors required for EVAA’s situational awareness were wired into EVAA. Build two is where EVAA

is allowed to control the aircraft by activating autopilot maneuvers within the aircraft’s flight control system. In this phase, the pilot or ground control operator throws a switch to tell EVAA to initiate one of the many avoidance maneuvers EVAA can use. This is called the pilot activated recovery system (PARS) phase. At the beginning of May, EVAA began successfully flying the PARS maneuvers in the simulator.

“PARS testing is when we gain an accurate understanding of the aircraft and autopilot dynamics. This is used to build models to predict how much space the various avoidance maneuvers will require to avoid the ground and other aircraft.” Brown said. “iGCAS and iACAS will use these models to understand which maneuvers will work best and when they need to begin an avoidance.”

Build three brings iACAS and iGCAS into EVAA and the system will begin to show its true potential. EVAA will react to other aircraft and the ground and the safety it provides becomes tangible. The final build, build four, will bring on many additional monitors and sensors such as the forced landing system, well clear, geo-bounding, in-flight route replanning and a host of health monitors.

X-plane Demonstration

When California instituted the stay-at-home order for COVID-19, the project was preparing to begin the PARS phase flight test. Unable to conduct flight testing, the team made an immediate pivot to in-home simulation to allow progress to continue on software development. Instead of hosting in-person, the DOD and FAA X-plane iGCAS sim demo for EVAA was displayed through Microsoft Teams. The project software lead Ethan Williams flew the demo for the group from his computer at home to show maneuvers and capabilities. Full

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Simulator



AFRC2020-0108-03

NASA/Ken Ulbrich

Derek Abramson and Robert Jensen assemble pieces of the Hybrid Quadrotor 90C (HQ-90) at NASA Armstrong’s Dale Reed Subscale Flight Research Lab.

HQ-90 arrives

By Teresa Whiting

Armstrong Public Affairs

The L3Harris built Hybrid Quadrotor 90C (HQ-90) arrived at NASA Armstrong on Sept. 30 and was transferred to the center’s Dale Reed Subscale Flight Research Lab on Oct. 1. Engineers Derek Abramson and Robert Jensen assembled the aircraft for the Resilient Autonomy project.

When the aircraft is ready to fly the team will perform flight tests in a variety of scenarios using the Expandable Variable Autonomy Architecture (EVAA) software.

The project will test the software and inform airworthiness

HQ-90, page 6



AFRC2020-0108-25

NASA/Ken Ulbrich

Abramson and Jensen install a wing on the Hybrid Quadrotor 90C (HQ-90) at NASA Armstrong’s Dale Reed Subscale Flight Research Lab.

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EVAA hardware was coupled to the X-plane sim to exercise the algorithms of EVAA and to demonstrate EVAA running on the flight hardware.

The pilot in this case used a joystick to fly and EVAA interrupted when it saw safety issues. The X-plane sim creates all the signals that would normally come from sensors off the aircraft and go into EVAA. EVAA is sending commands out to an autopilot in X-plane and then the system controls the aircraft.

“Under this telework environment, there is one person at the controls, which would not be our normal mode,” Skoog said. “They are having to not only fly the aircraft like a pilot, but they are having to exercise all the flight test support functions that would normally be distributed among a number of people on the ground.”

Flight Testing with the HQ-90 Aircraft

When flying is re-opened, the team will perform flight tests in a variety of scenarios using EVAA. Research pilots at Armstrong will train for these missions and collect data. Flight tests will use the L3Harris Hybrid Quadrotor 90C (HQ-90), which is a 120-pound vertical lift and transition remotely piloted aircraft featuring an 8-to 22-pound payload capacity with a long endurance flight time of



AFRC2020-0108-27

NASA/Ken Ulbrich

The Hybrid Quadrotor 90C (HQ-90) is displayed outside the NASA Armstrong's Dale Reed Subscale Flight Research Lab. The Resilient Autonomy project will use this vertical lift and transition remotely piloted aircraft for software testing.

12 to 22 hours, depending on the payload.

Future Framework

In parallel with flight-testing, an airworthiness approach to certification, design, and airworthiness approval is being conceptualized with the FAA, recognizing the limitations of data being collected in simulation. The approach hopes to leverage a

common framework of the EVAA system that can be potentially used on aircraft ranging from general aviation retrofit to future autonomous aircraft.

“Our method is to lead by building a reference implementation of a highly autonomous aircraft, imbed within that aircraft decision making algorithms, show how that decision making should be

harmonized and bring forward data artifacts for community review (primarily the FAA) and document the results,” Skoog said. “We are leading the industry by building a widget that is a working system capable of the levels of the autonomy envisioned to exist in the future, and hope to show how we think that vehicle could operate safely without a human in the loop.”

HQ-90... from page 5

requirements to enable future autonomy, such as link-less operations in an unpowered aircraft, while also providing enhanced automated safety to modern piloted aircraft.

In parallel with data collection from flight-testing and simulation, the Federal Aviation Administration is developing a certification approach that could leverage a common framework of the EVAA system for potential use on aircraft ranging from general aviation retrofit to future autonomous aircraft.

This HQ-90 named “Lewis” is a hybrid vertical takeoff and landing (VTOL) fixed-wing remotely piloted aircraft featuring an 8-to

22-pound payload capacity. The aircraft has a long-endurance flight time of 12 to 22 hours, depending on the payload. The HQ-90 is 120 pounds, 98 inches long and has a 185-inch wingspan.

A second HQ-90 named “Clark” is set to arrive at Armstrong in late 2020. This second aircraft will have integrated acoustic sensors in the custom-made wings to help detect air traffic. Also included in the shipment will be a second set of these wings to replace the wings on the first aircraft. One vehicle will remain at the center and the second vehicle will be transferred to the U.S. Department of Defense.

Jeanette Le is hard at work as a super swabber in her costume judged to be the best in the 2020 in a Costume category.



Skylar Antoniewicz



Shannon Jeffers

Cindy Jeffers shows off her flamingo, which was judged to be the funniest costume.

Halloween high jinks

The Annual Armstrong Chili Cookoff and Costume Contest went virtual this season and offered a howling good time.

The costume contest winners included:

- Funniest costume was awarded to Cindy Jeffers and her flamingo.
- Kate McMurtry won for most creative costume as a blessing in disguise.
- Tom and Avalon Jones and daughter Lila, who were dressed as Paddington and friends, were

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Tom Jones

From left Avalon, Lila and Tom Jones recreate Paddington Bear and friends. At right is another look at Lila's costume. The family won the Mini-Me category.

Kate McMurtry took a unique approach to her costume, which the contest judges identified as the most creative.



Personal photo



Kirsten Boogaard

Phyllis Fogg and Charlie "Rocket Dog" Boogaard won the Judge's Choice award.

SOFIA... from page 2

models and NASA's Lunar Reconnaissance Orbiter data, pointing out that water could be trapped in small shadows, where temperatures stay below freezing, across more of the Moon than currently expected. The results can be found here.

"Water is a valuable resource, for both scientific purposes and for use by our explorers," said Jacob Bleacher, chief exploration scientist for NASA's Human Exploration and Operations Mission Directorate. "If we can use the resources at the Moon,

then we can carry less water and more equipment to help enable new scientific discoveries."

SOFIA is a joint project of NASA and the German Aerospace Center. Ames manages the SOFIA program, science, and mission operations in cooperation with

the Universities Space Research Association, headquartered in Columbia, Maryland, and the German SOFIA Institute at the University of Stuttgart. The aircraft is maintained and operated by NASA Armstrong Building 703 in Palmdale.

Halloween... from page 7

judged to be the best in the Mini-Me category.

- Jeanette Le and her super swabber costume was a hit in the 2020 in a Costume category.

- The Judge's Choice went to Kirstin Boogaard's concept of a pilot (her mom Phyllis Fogg) and spaceship (Charlie "Rocket Dog" Boogaard).

In the chili contest, Nic Heersema captured the People's Choice and Judge's Choice categories with the Fall Winds Comfort Vegetarian Chili. Because the contest wasn't live, the winner had to give a description to entice the judges.

The winning description Heersema wrote: When the fall winds blow cold and whisper that winter is coming and you are just craving comfort food, this is the chili you want to eat. This hearty chili warms your belly without setting your mouth on fire, perfect for the cold nights and warm days of autumn. Packed with sweet potatoes and three kinds of beans, I started making this for chili cook-offs so my vegetarian friend wouldn't feel left out. These days I make it for myself because it is just that delicious (and really simple to make). Of course,



Nic Heersema

Here's a heaping portion of Fall Winds Comfort Vegetarian Chili.

what chili would be complete without some cheese and cornbread?"

Special thanks to Robbin Kessler and the participants for their contributions to this feature.

Juan Santos, 35-year contractor, dies at 66

Juan Santos, a contractor at NASA Armstrong for 35 years, died Nov. 2. He was 65.

Santos started working at the center as a Lockheed

Martin contractor in 1985. His started his career at the center as a communications specialist and was promoted to aircraft battery technician. Santos joined Kay

& Associates Oct. 1, 2011, also as an aircraft battery technician. He later added lifting device tester to his duties.

He was a diligent and

enthusiastic about his job, great to work with, loyal and a dedicated family man, according to people who knew him.

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