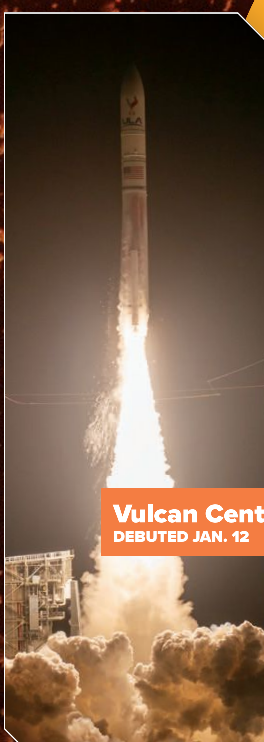
AEROSPACE
★ ★ ★ AMERICA ★ ★ ★

2024 YEAR-IN-REVIEW

FOUR FIRSTS FOR ROCKETS



Vulcan Centaur
DEBUTED JAN. 12

H3 FIRST CUSTOMER LAUNCH, JULY 1

Ariane 6
DEBUTED JULY 9

Super Heavy
TOWER CATCH, OCT. 13

PLUS

Boom's first flight and dozens of other breakthroughs

DECEMBER 2024 | A publication of the American Institute of Aeronautics and Astronautics | aerospaceamerica.aiaa.org

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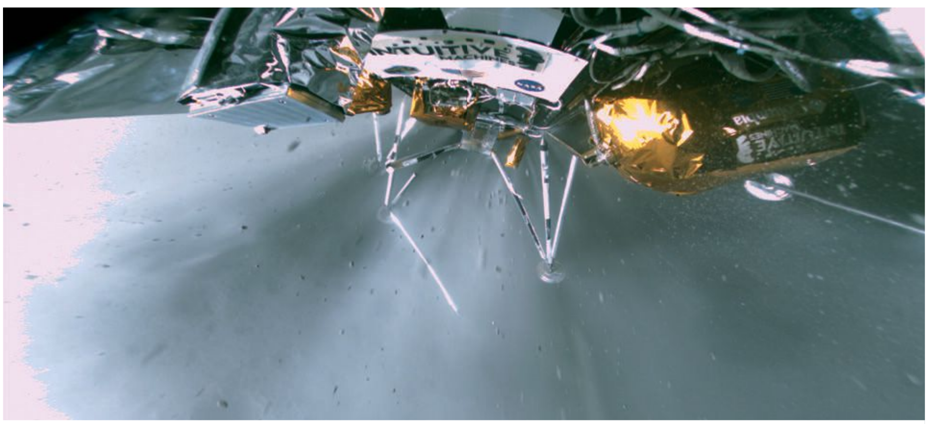
HORIZON
UNLEASHING INNOVATION
TO PROTECT THE WORLD
MAXAR
SPACE SYSTEMS

The Year-in-Review

The most important developments as described by AIAA's technical, integration and outreach committees



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Intuitive Machines in February became the first company to land a spacecraft on the moon. Results were mixed.

Intuitive Machines

PAGES 23, 26, 37, 48

Artificial intelligence algorithms controlled the X-62A VISTA test aircraft in a dogfight exercise against a piloted F-16. U.S. Air Force

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China's Chang'e-6 capsule landed in June, carrying the first samples retrieved from the far side of the moon.

China National Space Administration

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YEAR IN REVIEW

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Aerospace America presents readers with independently produced news and feature articles and a rich variety of opinions relevant to the future of aerospace. The views expressed in these pages are not necessarily those of our publisher, AIAA.

AEROSPACE AMERICA

DECEMBER 2024, VOL. 62, NO. 11

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SHAPING THE FUTURE OF AEROSPACE


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EDITOR'S NOTEBOOK

Two possible space strategies for the Trump administration

What will our Year-in-Review issues look like for the next four years with President-elect Donald Trump at the helm in the United States?

I predict that the research themes won't vary much from what we saw in the Biden years and the first Trump administration. These themes — artificial intelligence, electric flight, biofuels, hypersonic weapons, extending society into space — do not depend solely on the United States, and they are governed by market forces and security needs that are beyond the control of any single administration. If there's going to be a large-scale disruption, it's more likely to happen at the flagship level and involve the Artemis moon program and its relationship to Elon Musk's plans for getting humans to Mars.

In the present architecture, the moon is a proving ground for the Starship concept and a source of at least $4 billion in revenue for Musk's Mars aspiration. For NASA, the moon is an opportunity for the U.S. and its allies to outshine China in human exploration and scientific discovery. After the November Starship launch, NASA Administrator Bill Nelson described the partnership with Musk and SpaceX as follows: "Starship's success is Artemis' success. Together, we will return humanity to the moon."

But now, a new dynamic is at hand, given the close political relationship between Trump and Musk. This dynamic seems sure to produce big changes, and here are two possible shifts of strategy:

1) NASA becomes almost like a subcontractor to SpaceX and helps Musk achieve his Mars aspiration. NASA's Space Launch System rockets are relegated to history, and the Artemis program is recast as a Mars program, with Starships becoming the means to get there. This path would be disruptive, but the political triumphant of landing on Mars almost certainly could not be pulled off in four years, even by SpaceX.

2) NASA's research and development portfolio is increased vastly to put the agency in a role similar to that of the 1950s, '60s and early '70s, when its propulsion and vehicle research got us back to the moon and gave us the space shuttles. The SLS rockets are relegated to history in this strategy too. The moon becomes a NASA-funded testing ground for Starship alone. U.S. astronauts arrive during the Trump administration, delivering a political and technical triumph.

The second possibility has a potential long-term benefit: When I imagine civilizations far more advanced than ours on exoplanets, I don't picture them getting to space by lighting up 33 engines in a cloud of lethal exhaust. They probably had a forceful personality like Musk early on to help break the cost curve and prove the feasibility of reusing spacecraft. But their society didn't stop there. They needed an agency akin to NASA to keep pushing the possibilities forward through research on fuel, fundamental physics, quantum mechanics, materials and more.

So far, SpaceX and Musk have done an indisputably masterful job of innovating with conventional technologies, but there are limits to what can be achieved this way. Ask yourself: What technologies will the next Elon Musk have available to build on? If the incoming administration and the next ones are not careful, the answer could be some amazing discoveries by China. ★

Ben Iannotta, editor-in-chief, beni@aiaa.org

Letter: Missing the point of ISS

In his October Editor's Notebook, "Finishing strong," Ben Iannotta wrote that the International Space Station program has had "no moderating effect on Russia." Associate Fellow Jim Van Laak wrote to offer a different view:

To be honest, I think you missed the forest for the trees. No doubt you are too young to have many memories of the Cold War, but as someone who lived at the tip of the spear at its height, it was one of the most significant aspects of the 20th century. The advent of nuclear weapons at the end of WWII gave humanity the ability to extinguish human life on this planet, but not the wisdom to avoid this fate. Never before had humanity faced such a threat, which my generation was forced to confront directly. Imagine if your 8-year-old children were doing "Duck and Cover" drills in school and your parents were debating whether a fallout shelter was sufficient or a blast shelter was required in the basement.

When Space Station Freedom was created in 1984, it was a typical NASA program to extend our reach with a long-term presence in space. Unfortunately, it lacked a vision worthy of the cost and a management team worthy of our trust. When Bill Clinton was elected with the promise to balance the budget, it was soon on the chopping block. Dan Goldin negotiated the opportunity to lower the cost and increase the value of the effort, resulting in the International Space Station. The redesign itself was uninspired, but the decision to add our former Cold War adversaries elevated the pedestrian to the sublime. For those of us who had seen the nuclear threat in intimate detail, it was a breakthrough moment and a powerful personal motivator.

I was one of the original leaders of the new station program (brilliantly named Alpha and later renamed ISS), given the job of finding a programmatic and technical approach to integrating this foreign element into the remains of the Freedom design. In 2014, ISS was nominated for the Nobel Peace Prize, and I am confident it will win when it is retired.

ISS also has taught us some powerful lessons about how to succeed in space. Its approach to building a huge system in flight, maintaining reliability and function as elements are added and moved around, opens the door to entirely new visions of exploration systems. The experience of keeping people safe and healthy in space is irreplaceable.

Jim Van Laak, AIAA Associate Fellow | Poquoson, Virginia
Jim was an Air Force fighter pilot before joining NASA in 1990 and becoming the director of risk management on the Space Station Alpha Program at Johnson Space Center in Texas.

Author's response: *I do have strong memories of the Cold War. In college, most of my dorm watched "The Day After" on TV in 1983. Let's not go back to that. — Ben Iannotta*

FLIGHT PATH

Welcoming Clay Mowry

Clay Mowry began his tenure as AIAA CEO in October. He comes to AIAA with a wealth of experience in the aerospace industry and a career-long dedication to supporting students and young professionals. Clay recently shared more about his own career path and his outlook for AIAA. The following column summarizes a conversation at AIAA's offices in Reston, Virginia, as he dives into his role.

Why did you choose aerospace as your line of work?

Like any kid, I was fascinated by airplanes and the space program. But I never really thought about it as being a career option. Aerospace kind of found me. As I shared before, my career began in the U.S. Department of Commerce's Office of Aerospace, after I finished grad school at Georgetown University. Within three months of taking that job I was in Moscow as part of a U.S. delegation that was negotiating a commercial launch agreement with the newly formed Russian space agency, Roscosmos. Everybody else on the delegation was far, far senior to me. I was still in my mid-20s. As a kid who grew up in the 1970s and 1980s in the Cold War generation, it was fascinating for me to be in the former Soviet Union going to the facility where they were building Proton rockets. It was a seminal moment where I thought, "Wow, this is something I can do as a career, something that could be a lot of fun and have a real impact in terms of what we're trying to do as a country."

PAST POSITIONS

2021–March 2024, chief revenue officer at Voyager Space, the Colorado company developing the Starlab commercial space station with Airbus and others

2016–2021, vice president of sales, marketing and customer experience at Blue Origin

2001–2016, president and chairman of the U.S. subsidiary of Arianespace

1995–2001, founding executive director of the Satellite Industry Association

NOTABLE

- Joined AIAA in 2006; Class of 2024 AIAA Fellow
- Founder of the Future Space Leaders Foundation, a nonprofit focused on assisting young professionals in their career development
- Advisor to Vast, a commercial space station developer in Long Beach, California
- President of the Paris-based International Astronautical Federation for a term ending in October 2025
- Adjunct Professor, Science, Technology and International Affairs Program (STIA), Georgetown University, starting November 2024

EDUCATION

- Bachelor of Arts in politics and government, Ohio Wesleyan University
- Master of Business Administration in marketing and international business, Georgetown University

How did you become involved with AIAA?

I left the U.S. government to help start the Satellite Industry Association. I took that job because I thought it would be intellectually interesting to work on all the issues related to the satellite industry and I would get to meet all the leaders of that sector. After that I worked for Arianespace, which was at the time the world's leading commercial launch company. I started getting involved in the local AIAA section in the Washington, DC, area, doing public policy and really getting involved on the space side of the Institute. After a few years of paying dues, I took the plunge and became a lifetime member.

Who are some of the business leaders that inspire you?

I'll go back to my days at Georgetown University, when I was getting my MBA. John Dealy was my professor of strategic management, and he had been the President of Fairchild Industries. I love the way that he viewed teaching at Georgetown as a way to give back, to train a next generation of leaders and to get people passionate about space. He also taught me basic things about management, like the four principles of being a general manager. First, have a plan about the direction of the organization. Second, have the right people and resources in place to execute on that plan. Third, communicate that plan effectively back to the team. And fourth, execute the plan and revise and refine it as you go forward.

Why does the community need AIAA?

Our value proposition is delivering information and connectivity to your professional cohort over the course of your career. AIAA is really in the information delivery business, trying to help get information to our members that is relevant to them during their career, so they can advance, learn, and thrive in their jobs and be recognized for the work that they do.

The important piece of this is to be relevant to individual members throughout that entire career arc. From when you're starting to get interested in the field in middle school and high school. When you're studying in college and graduate school, we want you to be coming to our events, publishing your first technical paper with us, and being mentored by one of the more senior members. Then when you get out of school and start your first job, you're engaged in our regional activities and national events. As you progress in your career, you might chair a technical committee, start mentoring, giving back, and inspiring the next generations. You're getting recognized over the course of your career, coming to our awards events and meeting people from around the world. All of that is an information flow. Then, from a corporate member standpoint, AIAA should be a resource to recruit and retain the brightest minds.

What do you see as the unique needs of students and young professionals?

This is the most exciting time in aerospace! Tons of students and professionals are trying to figure out how to get jobs and progress in their careers in aerospace, so attracting them to our shows and events is job No. 1. If there are financial barriers to them attending or other things we can do to help bring them in, we've got to figure out how we can help. I'm still the president of the International Astronautical Federation, which puts on the annual International Astronautical Congress. This year in Milan, we had 11,200 people attend, and 37% of those who came and presented papers were students and young professionals. A lot of them get there under scholarships from their companies or their space agencies sponsoring them, or they share a room with friends to lower the cost. I want to figure out how to do more of that at AIAA forums.

Most of your background has been in space, so how are you getting to know aviation?

I started my career promoting U.S. aerospace products at the Dubai Airshow, Farnborough, and Le Bourget (Paris), just to name a few. I love airshows and I love the aviation side of AIAA. I'm really excited to get involved again. I couldn't think of a more exciting time for aviation than right now – when we talk about advanced air mobility, vertical takeoff and landing platforms, supersonic transport – there's a ton of excitement now. There's a lot of areas where we're seeing interest, new technology, and new ideas coming to light. I've got a little bit of learning to do to get up the curve, there's no doubt. I'm sure that sessions at our forums and events and our technical committees are going to help me get smarter quickly.

What is AIAA's role in advancing technology?

First and foremost, our technical committees and events help to advance the state of the art in technology areas by sharing knowledge, pushing the envelope, and attracting the next generation workforce. We have the credibility and obligation to speak on behalf of our membership to make sure that it's well known and understood where technology is going and where the industry is heading.

How can AIAA help with the commercialization of space?

Lowering the cost of launches and deploying more assets in space has opened a huge area of the sector to new companies and startups. There's also a tremendous amount of private capital moving into the market that is driving a lot of innovation. There are a lot more startups that are leveraging space. AIAA can help educate on the sustainability aspect of space – issues like norms and best practices that ensure that everybody can operate up there safely and securely. There's a huge focus on space situational awareness and coordination of activities in low Earth orbit. AIAA can play a role in this discussion by bringing together stakeholders to talk at our forums and events, people presenting papers on new technologies and areas where we can think about how we operate more safely and securely.

How would you describe the soul of AIAA?

It's super energizing to be here. It's been a pleasure for me to get to know the staff, to sit down and dig in on what we do and how we do it, then figure out together how we're going to lead going forward. The staff at AIAA is passionate about the mission and dedicated to our members. A big part of delivering member services is tied to our digital transformation – having infrastructure in place and communicating with our members through digital platforms. What we used to do in the analog world or in print or by email, now we've got to do all that on our phones. And how do we make all that information accessible to engineers? I'm really focused on the delivery of information and how we work to improve it. ★

Aeronautics-centered structural adaptivity shares the stage with extraterrestrial and transitional solutions

BY DARREN J. HARTL AND FRANCIS R. PHILLIPS

The work of the **Adaptive Structures Technical Committee** enables aircraft and spacecraft to adapt to changing environmental conditions and mission objectives.

▲ Researchers from the University of California, Davis and the U.S. Army Research Laboratory attached a birdlike tail to this small aircraft model for a series of wind tunnel tests. In future tests, they plan to install a similar tail to a different aircraft model to assess impacts on maneuverability.

U.S. Army Research Laboratory

This year's adaptability achievements centered on aeronautical challenges, especially wing-related ones. A team at the **German Aerospace Center, or DLR**, explored the use of **hyperelastic solid-state joints** to bond the lower and upper skins of a prototype wing to a variable camber trailing edge. In February, tests on an **airfoil segment** showed that large morphing deformations are possible with very low actuator forces. In July, they proved that **spanwise differential cambering** is also possible with this approach. These findings are being transitioned to flight tests with **unoccupied aerial systems, UAS**. Researchers predict that a higher aerodynamic efficiency can be achieved while keeping the aircraft weight roughly equivalent.

With aerodynamic modeling, researchers at the **University of California, Davis** predicted the effects of **avianlike morphological changes**, including wing sweep, wing dihedral, wing extension, wing airfoil incidence angle, wing camber, tail spread and tail incidence. In June and July, in collaboration with the **Army Research Laboratory** in Maryland, they completed wind tunnel tests that explored the role of birdlike tail morphing to enhance perching capabilities. These new results will be combined with previous bird flight studies, low-fidelity models and artificial intelligence to identify coupled **wing-tail morphing patterns** for a small UAS, on which they will test advanced maneuvers.

Between June and October, a team at **Texas A&M University**, in collaboration with **NASA's Langley Research Center** in Virginia, completed a wind tunnel model to examine the efficiency of a **slat gap filler** in reducing aeroacoustic noise, with testing planned over the next year. With the model-scale **NASA-Boeing Common Research Model** wing, they plan to study the aerodynamic and aeroacoustic behavior of a deployable gap filler for the first time. A slat gap filler reconfigures the recirculation region beneath a leading-edge slat, reducing noise radiated from the wing to observers on the ground, especially during landing.

Regarding lunar research, **Texas A&M** researchers, in collaboration with **NASA's Johnson Space Center** in Texas, have developed and tested a shape memory alloy **torque tube thermosiphon**, a type of passive heat management device. In September, they evaluated the thermosiphon in combination with a **rotating radiator panel** that provides heat rejection. Going forward, this subsystem is to be integrated with a **fuel cell simulator** to verify its operational effectiveness and its ability to survive the lunar night. The combined system could enhance the reliability and extend the operating life of lunar fuel cells while reducing thermal control complexity.

Of special interest this year was the transition of aerospace-originated concepts to new research sectors. In March, researchers at **Concordia University** in Quebec developed an accurate, computationally efficient **nonlinear dynamic model** and **AI-based control algorithms** for a 4D-printed, adaptive magnetoactive **soft continuum robot**. This robot, attached to a surgical wire, can navigate intricate brain pathways to deliver **therapeutic treatments** for strokes and aneurysms, including drug delivery, clot ablation and stent deployment. In a manner similar to that observed in aerospace vehicles, the innovative AI-driven control algorithm allowed the robot to accurately follow predetermined neurovascular paths in a custom-made vascular phantom, significantly improving the effectiveness of minimally invasive surgeries. This could pave the way for **autonomous robotic platforms** that reduce patient recovery time and costs. ★

▲ Between March and mid-November, Boom Supersonic of Colorado conducted eight subsonic flight tests with its XB-1 demonstrator. This subscale aircraft is to help the company refine the design for its planned Mach 1.7 airliners, the Overtures, which Boom wants to begin delivering in time for passenger service to begin in 2029.
Boom Supersonic

New designs and technologies shaping the future of aviation and space exploration

BY LISA SAAM

The **Design Engineering Technical Committee** promotes the development and dissemination of technologies that assist design engineers in defining practical aerospace products.

Many new aerospace designs and technologies continued to be developed at an exhilarating pace. From lunar exploration to supersonic flights, these developments will shape the future of aviation and space exploration.

In February, the **Odysseus** robotic lander from Texas-based **Intuitive Machines** landed at the lunar south pole. Although Odysseus tipped over shortly after landing, this was the first time a private U.S. spacecraft had touched down softly on the moon. The lander carried 12 payloads, six from **NASA's Commercial Lunar Payload Services program** and six from commercial entities.

One payload of particular interest was the **Navigation Doppler Lidar** sensor developed by **NASA's Langley Research Center** in Virginia. NDL addresses the need of future robotic and crewed planetary missions for precise **ground-relative velocity vector and altitude data**, which is required to execute complex descent maneuvers toward a safe, soft and pinpoint landing at a predesignated site. NDL operated flawlessly during the descent, measuring velocity and range along each of its three laser beams. The precision was better than 0.8 centimeters per second for velocity measurements and 0.8 meters for range measurements.

In February, Astroscale's **Active Debris Removal by Astroscale-Japan** spacecraft was launched on an **Electron r**ocket from New Zealand. **ADRAS-J** performed a controlled fly-around of a discarded rocket upper stage while capturing images from various angles and lighting conditions, essential information for a future planned mission to capture and remove the debris. This marked the first time a private spacecraft had rendezvoused with an unprepared object.

In March, **Stratolaunch** of California announced that it completed the first powered flight with a **Talon-A** test vehicle, TA-1, a major milestone in the development of the first privately funded, reusable hypersonic test vehicle in the U.S. TA-1 accomplished a safe air launch, engine ignition, acceleration to supersonic speeds approaching Mach 5, a sustained climb to altitude and a controlled water landing.

In March, Colorado-based **Boom Supersonic's XB-1 demonstrator** took off for the first time from **Mojave Air & Space Port** in California, completing a 12-minute subsonic flight. During the second test flight, in August, the landing gear was retracted and extended and a new roll damper was assessed. The environmental control system was evaluated during a third test flight in September, along with additional tests of the landing gear actuation at higher speeds. With these flights, Boom is testing some of the technology for **Overture**, its planned Mach 1.7 airliners.

In April, **BETA Technologies** of Vermont achieved its first piloted transition with a prototype of its **ALIA A250,** an **electric vertical takeoff and landing** aircraft. After a vertical takeoff in New York, the A250 transitioned to forward flight and then back for a vertical landing. This was a first step toward BETA's "lift and cruise" approach to runway independence.

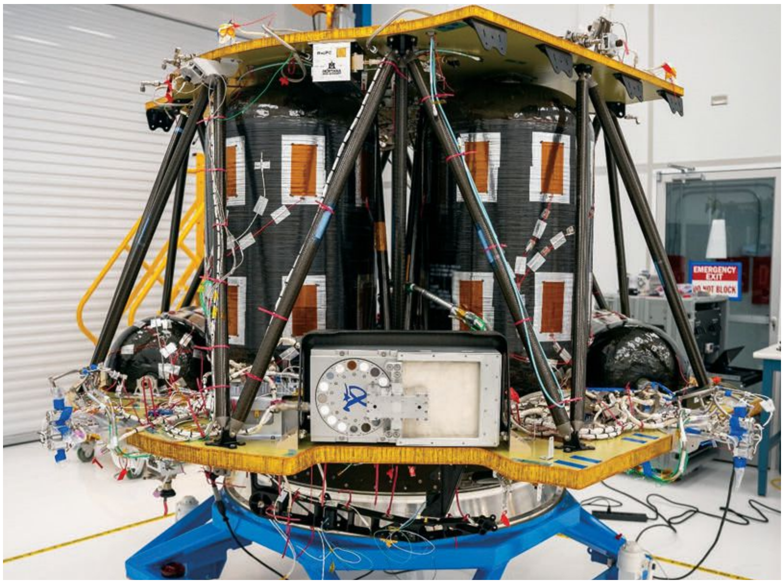
This year, a wave of **generative artificial intelligence** took over the design and simulation world. In April, **Ansys**, a leading finite element simulation software company based in Pennsylvania, announced the release of its AI-powered virtual assistant. **AnsysGPT** is to provide a secure, easy-to-use interface with real-time responses in numerous common languages. In July, **Altair** of Michigan released **Altair Hyperworks 2024**, a design and simulation platform that embeds AI to accelerate design exploration and iteration via generative design capabilities. Also in July, Texas-based **Siemens Digital Industries Software** announced additional AI-enabled design capabilities in its **NX CAD** software to improve efficiency in optimizing and validating designs. ★

Contributors: *Kyle Benson, Anna-Maria McGowan and Manasi Palwankar*

Innovations in design and test for the new space frontier

BY TERRISA DUENAS

The **Materials Technical Committee** promotes interest, understanding and use of advanced materials in aerospace products where aerospace systems have a critical dependency on material weight, multifunctionality and lifecycle performance.



▲ The silver box in the middle of this picture contains samples of polymers and metals that were scheduled to be landed on the lunar surface in November or December. Investigators plan to photograph the materials to document the effects of the lunar regolith on them. The payload was installed earlier this year aboard a Firefly Aerospace Blue Ghost lander.

Firefly Aerospace

In March, researchers at **NASA's Glenn Research Center** in Ohio developed the **Automatic Information Management Across Organizations and Scales** digital thread maintenance tool, a **multiscale analysis framework** for a composite structure, with individual simulations tools defined for the nano-, micro-, meso- and macroscale, to judiciously automate the computational workflow. This tool, and other frameworks that connect with **information management systems**, are critical for true integrated computational materials engineering design of materials and structures, because they allow engineers to apply rapid simulation-based approaches to material/structural design and selection, with full material traceability across its lifecycle. Such frameworks can be paired with **optimization algorithms** to concurrently design **fit-for-purpose materials** and **optimized application geometries**, which help reduce costs and time-to-market for engineering applications while ensuring that the digital twins and digital thread for that application are properly maintained. **Integrated computational materials engineering** is heavily predicated on the availability and use of multiscale physics-based and data-driven simulation tools, so such tools require large amounts of data for characterization and verification and validation. Organizations must implement robust information management systems that effectively manage material information.

In May, Pinar Acar of **Virginia Tech** and Md Maruf Billah, her Ph.D. student, designed **tailored microstructures** and quantified the uncertainty of meso-scale mechanical properties of the **Ti-7A alloy** that is widely used in aircraft structures. They demonstrated a novel technique for designing microstructures, applying an **analytical uncertainty quantification method** to target exact design-under-uncertainty solutions. The researchers considered single-crystal-level epistemic uncertainty arising from molecular dynamics and microstructural-level aleatoric uncertainty, measured by experimental techniques for determining the meso-scale uncertainty. The approach was utilized to propagate the uncertainty, which is further incorporated into the design of microstructures for the desired mechanical properties of Ti-7Al. This design-under-uncertainty strategy for microstructures can exhibit high performance and reliable mechanical components for aircraft structures. These findings could also impact the design and manufacturing of future advanced materials by providing a pathway for engineers and technicians to develop and produce metallic alloys with tailored properties for specific applications.

In March, **Aegis Aerospace Inc.** reported that its first lunar materials science payload, the **Regolith Adherence Characterization Facility, RAC-1**, was integrated aboard a **Firefly Aerospace Blue Ghost lander**, scheduled to touch down on the lunar surface later this year on a mission under **NASA's Commercial Lunar Payload Services program**. Funded by NASA, RAC-1 contains two sets of samples of 15 different polymers and metals, some covered with dust repellent coatings. **Lunar regolith dust** is highly abrasive and can cause erosion and electrostatic issues, so scientists will expose the samples to the lunar environment to analyze how they interact with regolith dust. The samples reside on two wheels placed on the surface of the RAC-1 payload. One of these wheels will be exposed in transit and during the lunar landing to get the full effect of the **regolith plume** generated when Blue Ghost touches down. The other wheel will be shielded by a cover, which will retract after the landing dust settles to allow for long-term exposure of the samples. Over the the 12-day investigation, the wheels will rotate every 24 hours so each sample can be photographed by a camera tower located in the center of RAC to monitor for erosion and dust accumulation. These images could provide valuable data on the interaction of polymers, metals and coating with lunar regolith dust. ★

Contributors: *Pinar Acar, Brandon Hearley and Jessica Piness*

Advances in analytical and computational processes improve vehicle optimization

BY GIUSEPPE CATALDO

The **Multidisciplinary Design Optimization Technical Committee** provides a forum for those active in development, application and teaching of a formal design methodology based on the integration of disciplinary analyses and sensitivity analyses, optimization and artificial intelligence.

In February, researchers at **ONERA, the French national aerospace research center**, released the **Surrogate Modeling Toolbox 2.0**. This new version includes features that have proven highly useful for engineering design in general and for the multidisciplinary design optimization community in particular, especially for **modeling, optimization and uncertainty quantification** purposes.

In June, the **Multiscale Multiphysics Design Optimization Laboratory** at the **University of California, San Diego** released **ParaLeSTO-COMSOL**, an extension of the Parallel Level-Set Topology Optimization code introduced last year. ParaLeSTO-COMSOL leverages COMSOL's graphical user interface to streamline the setup of finite element analysis, while a short MATLAB script integrates this process into an optimization framework. Designed to foster multidisciplinary collaboration and enhance education in topology optimization, the tool has been integrated into UC San Diego's graduate-level courses on topology optimization and additive manufacturing. It has proven effective for tackling complex optimization challenges, including **plasticity** and **conjugate heat transfer** with turbulence.

Researchers at **MIT's Engineering Systems Laboratory** in Massachusetts continued to develop **miniMDO Python** with funding from **Airbus**. This software package facilitates the formulation of monolithic MDO architectures for problems with analytic disciplines, objectives and constraints. The package also has a module to reformulate the problems based on **sparsity structure**. The codebase, which is still experimental, can be found on GitHub.

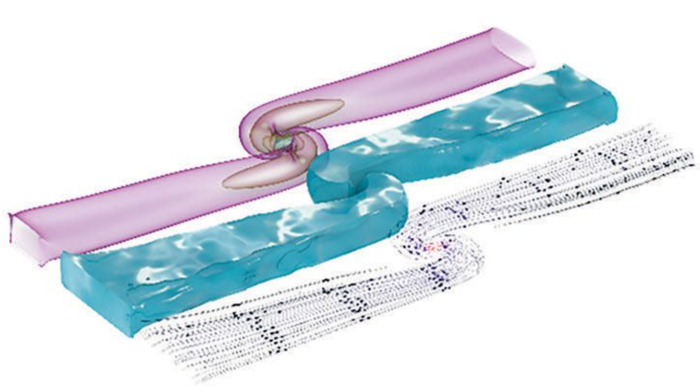
Researchers in the **Computational Optimal Design of Engineering Systems Laboratory** at the **University of Arizona** developed a multifidelity approach for the construction of **surrogate aerodynamic databases** based on computational fluid dynamics simulations and wind tunnel tests. Through an adaptive sampling and model fidelity management scheme, the **Gaussian process-based approach** limits the number of expensive simulations or tests while accounting for various sources of uncertainty. This year, researchers applied the approach to heat flux predictions on high-speed vehicles.

In July at **NASA's Goddard Space Flight Center** in Maryland, a group of researchers, in collaboration with the **NASA-funded Jet Propulsion Laboratory** in California and **Bocconi University** in Italy, upgraded the **Quantification of Uncertainty Analysis Toolkit, or QUAnT**. This set of computational tools efficiently quantifies uncertainty to guide the design process of complex, multidisciplinary systems throughout their lifecycles and under limited resources. Based on multifidelity modeling and efficient sampling techniques, QUAnT performed global sensitivity analyses and risk assessments for **NASA's Mars Sample Return** program, demonstrating improvements in computational cost and maximizing the value of information that can be extracted from a limited number of tests due to budget and schedule constraints.

In January, researchers at **Virginia Tech**, in collaboration with **Northrop Grumman**, developed an advanced framework for multidisciplinary structural analysis and design optimization of spacecraft structures by innovatively integrating commercial software and open-source Python libraries to facilitate easy implementation in aerospace industries. The framework can efficently optimize **composite space vehicle structures** for a range of **mechanical, thermal and acoustic loads**, with the help of an innovative approach that uses lamination parameters and mixed integer programming techniques to reduce optimization costs by some 60% compared to widely used **meta-heuristic algorithms**.

In September, **Virginia Tech** researchers also demonstrated an efficient **parametric reduced-order modeling technique** to optimize composite structures. They achieved a 97% reduction in analysis cost and a 99.9% reduction in memory requirements compared to its full-order counterpart in optimizing tow-steered fiber composite panels. The researchers are also developing an MDO code for aircraft design and performance analysis using liquified natural gas. LNG is environmentally friendly and cost-effective, has 26% more energy density than classical jet fuel and has vast reserves compared to currently used aviation fuels. ★

Contributors: *Youssef Diouane, Rakesh Kapania, Alicia Kim, Samy Missoum and Johannes Norheim*



▼ The University of California, San Diego released an extension of its Parallel Level-Set Topology Optimization code. In graduate courses, structural engineering students applied this code to determine the most efficient design for aircraft mechanical, thermal and fluid components. Here, multiple visualizations of a pipe were generated to optimize the flow of fluid.

University of California, San Diego

A groundbreaking year for uncertainty quantification

BY DANIEL L. CLARK JR. AND ERIN C. DECARLO

The **Non-Deterministic Approaches Technical Committee** advances the art, science and cross-cutting technologies required to advance aerospace systems with non-deterministic approaches.

▲ Plans call for Southwest Research Institute's Center for Accelerating Materials and Processes to open in the second half of 2025, with initial planned studies to focus on devising new manufacturing techniques for high-speed engines.

Southwest Research Institute

In June, **Southwest Research Institute, or SwRI,** broke ground on the **Center for Accelerating Materials and Processes**, a 3,200-square-meter facility for "research and development of high-speed aerospace engines," the organization said in a press release. Initial projects are to focus on "demonstrating faster, more efficient techniques for manufacturing high-speed propulsion systems," with probabilistic and **uncertainty quantification, or UQ**, approaches being applied to drive qualification of new manufacturing techniques.

In January, during **AIAA's SciTech Forum** in Orlando, Florida, the Fluid Dynamics Technical Committee hosted two special sessions on its proposed solution to a UQ challenge problem. During the session, meant to encourage engagement between the UQ and fluid dynamic communities, attendees compared the costs and strengths of different techniques. A follow-on challenge problem is under development.

Also in January, **SwRI** produced a first-of-its-kind study quantifying sources of uncertainty in aircraft structural integrity and lifing. With inspection and teardown data from the U.S. Air Force's T-38 fleet, researchers performed a **sensitivity analysis** of the equivalent initial flaw size distributions required for single flight probability of failure, or SFPOF, assessments. This study concluded that better characterization of crack growth rate uncertainty and alternative inspection methods below a certain crack size threshold would best reduce uncertainty in SFPOF.

In March, **SwRI** — in support of NASA's multiyear effort to determine the continued fitness-for-service of aging, noncoded layered pressure vessels — developed a critical flaw size analysis approach for cleavage fracture. The analysis employed the **NASGRO software** to guide nondestructive evaluation requirements. Recent developments included probabilistic approaches to understand uncertainty in geometry, loading and material properties and their impacts on critical flaw size predictions.

In May, **University of Maine** researchers explored UQ and design optimization methods to advance integrated process and product design of large additive manufacturing of fiber-reinforced thermoplastic and composite structures with the **Factory of the Future 1.0 printer**. The multifidelity modeling and simulation workflow relies on high-performance computing, with data-driven process-structure-property relationships accounting for uncertainties throughout the product realization process.

In July, the **Advanced Structures and Optimization Lab at Virginia Tech** proposed a novel methodology for UQ in magnetic phase transitions, effectively capturing long-range interactions and their effects on free energy and magnetization. The methodology highlighted the potential of quantum computing to address computational challenges in modeling of these complex systems.

In July, researchers from the **University of California, San Diego** and the **University of Michigan-Dearborn** introduced a new methodology for diagnosing and predicting pitting corrosion via multiscale simulations, a convolutional neural network and Bayesian updating.

In July, **SwRI** calibrated adhesive properties of a pi preform joint demonstration article, which are challenging to measure experimentally in the bonded joint configuration. This calibration was performed with **SwRI's CENTAUR tool** and is part of a multiyear program applying verification, validation and UQ methods to develop computational analysis tools to reduce testing of bonded 3-D carbon/epoxy textiles for certification.

From June to August, **SwRI** developed and applied a probabilistic workflow to characterize anomaly distributions of additive manufactured parts for risk-based life assessments. Anomaly distributions and exceedance curves are needed for **probabilistic damage tolerance analysis** of fatigue-critical aerospace parts, with the developed approach using extreme value statistics and additive manufacturing-specific adaptations for implementation in the **SwRI software DARWIN**.

In August, researchers from the **University of California, San Diego** proposed a new multifidelity method to estimate the entire distribution of quantities of interest of complex engineering systems. The method was demonstrated on a high-dimensional model, and its surrogate, to model the brittle fracture behavior of a fiber-reinforced matrix. ★

Contributors: *Pinar Acar, Barron Bichon, Andrew Cary, Ender Eger, Michael P. Enright, Zhen Hu, Laura Hunt, Matthew Kirby, Boris Kramer, Masoud Rais-Rohani, David Riha, Vicente Romero, Markus Rumpfkeil, James Sobotka and Marcus Stanfield*

On-orbit demonstrations and ground tests push technology forward

BY MANAN ARYA

The **Spacecraft Structures Technical Committee** focuses on the unique challenges associated with the design, analysis, fabrication and testing of spacecraft structures.

From small satellites to envisioned kilometer-scale systems, the development of **deployable structures** and **in-space manufacturing concepts** help lay the foundation for next-generation civil, defense and commercial capabilities in space. This year, several technology demonstrations were conducted, both in space and on the ground, to validate and advance novel concepts.

In April, an **Electron** rocket launched **NASA's Advanced Composite Solar Sail System, ACS3**, to Earth orbit. The goal of the mission is to demonstrate the unfurling of a **solar sail** via lightweight and thermally stable **carbon composite booms**. Mission operators confirmed successful deployment of the four 7-meter-long composite booms and the 80-square-meter solar sail in August. Solar sails can generate thrust indefinitely by reflecting sunlight — without needing consumable propellants — and are therefore advantageous for many mission profiles. In previous on-orbit demonstrations, the deployable booms that keep the sail taut have been metallic, and thus susceptible to bending and warping from solar heating. For ACS3, researchers at **NASA's Langley Research Center** in Virginia built the booms from carbon composite materials, which are expected to have much lower deflections than metal booms. If successful, ACS3 could lead larger solar sails to be developed and launched in the future.

Ground-based testing of an even larger solar sail system was completed in January, achieving technology readiness level 6. Engineers from **NASA's Marshall Space Flight Center** in Alabama, **Redwire** of Florida and **NeXolve** of Alabama unfurled one quadrant of a solar sail that when fully deployed will measure 1,650 square meters, the equivalent of four basketball courts. The sail was made of a durable **polymer film** 2.5 microns thick to save weight and allow for the sail to be accelerated to higher speeds when operating in orbit. Reaching TRL6 means the technology is available to be incorporated into future science mission proposals.

In January, **Caltech** announced the conclusion of its **Space Solar Power Demonstrator** mission, comprised of three payloads launched in January 2023 aboard the **Momentus Vigoride-5** space tug to test technologies of an envisioned constellation that would collect solar power in space and beam the energy back to Earth. Among the payloads was the **Deployable on-Orbit ultraLight Composite Experiment, or DOLCE**. For the future power stations, these frames would unfurl on orbit to hold **photovoltaic films** integrated with **radio frequency phased arrays**. DOLCE deployment began several months after launch, but the frame jammed on release — an effect addressed during ground testing but exacerbated in space. The Caltech flight team unjammed the structure through remote operation, an activity that underscored the importance of real-world testing while pushing the boundaries of current deployable structures technologies. Caltech said that the mission's lessons will guide design of the next-generation structure.

In March, **Dcubed** of Germany secured funding from the **European Space Agency** and the **European Commission** to develop and launch **in-space manufactured solar arrays**. Dcubed focuses on in-space manufacturing of large structures in addition to traditional methods of building such structures on the ground and unfolding them on orbit. The company said this funding will accelerate the development of next-generation solar arrays with support structures that are manufactured directly in space. ★

▼ Caltech in January concluded a year-long orbital test of technologies for future orbiting stations that could collect sunlight and beam it back to Earth for conversion into power. One technology was DOLCE, a 2-meter-by-2-meter frame that would hold photovoltaics and radio frequency arrays. DOLCE was unfurled last year from its space tug host. The sun and Earth are visible in this photo from the space tug.

Caltech/Sergio Pellegrino

A year of new dynamic tests and facilities

BY CRISTINA RISO AND RAFAEL PALACIOS

The **Structural Dynamics Technical Committee** focuses on the interactions among a host of forces on aircraft, rocket and spacecraft structures.

▲ As part of the preparations toward first flight of the X-59 supersonic flight demonstrator, NASA and Lockheed Martin this year completed various ground tests to verify the aircraft's structural dynamics characteristics. The aircraft is pictured here during a vibration and structural coupling test to verify its stability.

NASA's Langley Research Center

In January, **NASA** rolled out its **X-59 demonstrator** in a ceremony in Palmdale, California. In the following months, the project achieved several milestones toward initial flight tests, scheduled for early 2025. In March, NASA and prime contractor **Lockheed Martin** performed a **structural coupling test**, SCT. The aircraft's control surfaces were commanded to move by computer to ensure that the aircraft's servoelastic system operates as expected. Based on SCT results, engineers updated aeroservoelastic models. The X-59 project team also completed a flight readiness review in March to prove the aircraft's airworthiness. In a May news release, NASA described this review as "the first step in the flight approval process."

Also in March, a new **Mach-scaled rotor whirl tower facility** was completed at **Seoul National University's Siheung Campus** in South Korea. The first experiment, conducted in the same month, involved a trailing-edge flap rotor with a piezo-stack actuator. The 3-meter-diameter rotor rotated up to 1,100 revolutions per minute.

In May, researchers at **Sapienza University of Rome, Zurich University of Applied Sciences in Switzerland** and the **University of Southampton in the U.K.** completed a wind tunnel test campaign to characterize the **flutter onsets** and **limit-cycle oscillations** of a wing model exhibiting large aeroelastic deflections. By applying new operational modal analysis methods, they characterized the flutter mechanism at various wind tunnel speeds and wing root angles of attack. These experimental findings confirmed that the flutter speed is strongly affected by static wing deformations. The experiments, carried out at three wind tunnels at the participating universities, emphasized the strong effect that differences between wind tunnels can have on test results.

In July and August, **NASA and Boeing** tested the model for the **Integrated Adaptive Wing Technology Maturation subproject**, part of NASA's Advanced Air Transport Technology project. The model is based on an altered semi-span version of the NASA Common Research Model, with an increased wing aspect ratio and flexibility. Researchers aim to validate models and feedback control law design techniques for real-time drag minimization, maneuver load alleviation, gust load alleviation and active flutter suppression. The first test entry, conducted in the **Transonic Dynamics Tunnel at NASA's Langley Research Center** in Virginia, used heavy gas R-134a to test Mach numbers up to 0.80 and dynamic pressures up to about 190 pounds per square foot (over 13 atmospheres). Tests were conducted for envelope clearance, static aerodynamic characterizations and dynamic aeroelastic characterizations.

In August, **ATA Engineering Inc.** of California concluded numerical simulations of **Starshade**, a deployable structure being developed by **NASA's Jet Propulsion Laboratory**. The work correlated finite-element model deployment simulations to test data to ensure that the deployed shade would meet strict shape-accuracy requirements for this highly precise optical system. Throughout 22 deployment simulations, ATA demonstrated excellent agreement with test data in the random shape repeatability error, with a deviation of less than 5% between numerical and experimental results. This demonstrated that a numerical model can accurately predict deployment behavior and shape errors of an optical system, complementing physical testing throughout the design and verification process.

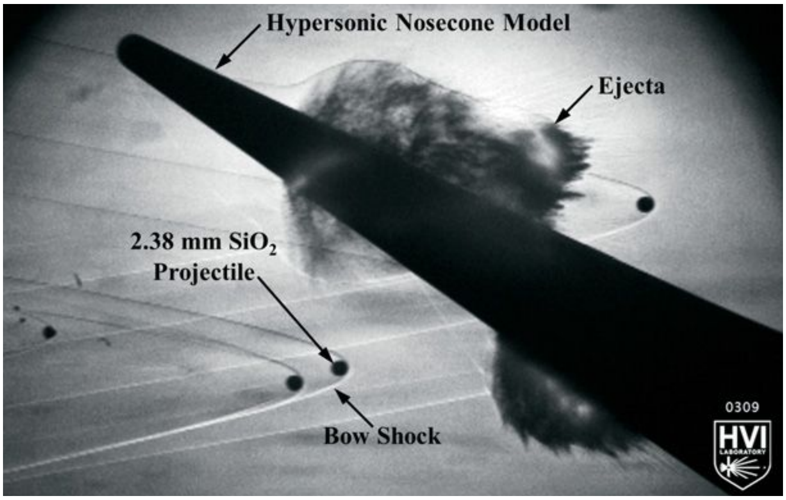
Building on the success of **NASA's Ingenuity Mars helicopter**, thin Martian rotors for aeroelastic testing were developed by the Rotor Optimization for the Advancement of Mars eXploration project, led by **NASA's Ames Research Center** in California**, with Caltech/JPL, AeroVironment, Tohoku University** and the **University of Maryland** as partners. Tests with the rotors, which have a 1% thickness in their outboard sections, could help engineers design larger, more capable Mars helicopters of the future. The full rotor tests were completed in September. ★

Contributors: *George Antoun, Eric Blades, Caitlin Clifton, Giuliano Coppotelli, Anubhav Datta, Jared Grauer, SangJoon Shin and Walter Silva*

Advances seen in high-temperature ceramic matric composites and in hypervelocity impact test facilities

BY EMILY ARNOLD AND CRAIG MERRETT

The **Structures Technical Committee** works on the development and application of theory, experiment and operation in the design of aerospace structures.



▲ Texas A&M researchers performed some 150 hypervelocity impact tests between December 2023 and June, including simultaneous, distributed particle impacts on hypersonic materials and structures.

Texas A&M/Thomas Lacy

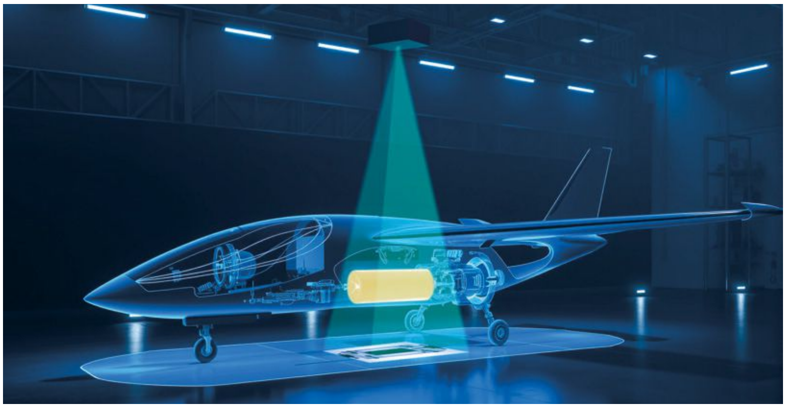
In June, researchers at **Mississippi State University** with **FAA** and **NASA's Langley Research Center** in Virginia concluded a study of **carbon composite T-joints**. These structural elements connect adjacent structural parts, such as wing skins to stiffeners, thereby providing the load path between structural components. Researchers fabricated and tested stitched **Vacuum-Assisted Resin Transfer Molding resin-infused T-joints** under pull-off conditions. Results indicated a 15% increase in ultimate load and an approximately 58% increase in energy absorption. The researchers demonstrated that through-thickness stitching significantly improves the damage tolerance of T-joints, highlighting the effectiveness of stitching in enhancing the structural integrity of large aerospace components.

Texas A&M University's Hypervelocity Impact Laboratory provides a high-throughput test bed for development and characterization of novel materials and structures subjected to normal and oblique HVIs over a range of velocities (0.1-8.0 kilometers per second), temperatures (minus 140 300 degrees Celsius), and pressures (5-760 Torr). Between December 2023 and June, Texas A&M researchers launched single projectiles and distributed particles via a coupled 12.7-millimeter bore single- and two-stage light gas gun to study applications in force protection, counter-hypersonics, micrometeoroid orbital debris impact mitigation and planetary defense. **Ultra-high-speed in-situ diagnostics** included laser velocimetry, shadowgraphy, particle/fragmentation tracking, Schlieren imaging, in-line holography and flash X-ray radiography. Aerosolized particles, including water and dust, introduced into the path of the incoming projectiles were used to assess shock-shock and particle-shock interactions. Results from this research are contributing to the development of the 1-km-long **Ballistic, Aero-Optics, and Materials Range** under construction at Texas A&M, as well as a 101.6-mm-bore single- and two-stage light gas gun.

Arizona State University continued developing a **validated computational framework** for modeling the nonlinear, time-dependent behavior of **ceramic matrix composites, CMCs**, at high temperatures and under sustained loading. In February, researchers created a deep learning-based framework to capture microstructure features and variability in CMCs with a **silicon carbide-based matrix**. Researchers use these microstructures in formulating a coupled creep-damage micromechanics model to capture complex load-sharing mechanisms. In June, they developed a multiphysics methodology and numerical scheme for modeling the multiregime oxidative response of CMCs, accounting for interactions between oxygen diffusion, matrix cracking, oxidation and stress at the microstructural scale. The team, in collaboration with **RTX Technology Research Center** in Connecticut, completed surrogate models for integration into CMC lifting codes using physics-constrained deep learning frameworks in November. Funded by the **U.S. Department of Energy** and the **Army Research Office**, this research will impact aircraft engines and land-based turbines that use CMCs by improving component reliability and failure prediction.

Composite materials with high strength-to-weight and stiffness-to-weight ratios are necessities for the aircraft industry. While these composites are already lightweight, reducing their weight further could improve aircraft performance and lower costs. One way to achieve this is through post-buckling design, although it comes with its own set of challenges, such as the identification of initial and progressive damage or failure modes after buckling. Preliminary **Abaqus analysis** completed in June by **Lockheed Martin** showed that by accounting for the impact of damage events on composite hat-stiffened panels as the weight changes under compression and shear loading, it's possible to reduce structural weight up to 16% without damage at loads higher than the critical buckling load. ★

Contributors: *Aditi Chattopadhyay, Vijay Goyal, Thomas Lacy and Rani Sullivan*



▲ Researchers at the Fraunhofer Institute for High-Speed Dynamics used a new high-speed X-ray imaging technique to create this high-fidelity model of an electric aircraft's battery packs. The technique would be used to analyze thermal runaway.

Fraunhofer Institute for High-Speed Dynamics/Michael May

Breakthroughs noted in space debris propagation, aircraft vulnerability and high-speed X-ray imaging

BY DOMINIC A. PENA

The **Survivability Technical Committee** promotes air and spacecraft survivability as a design discipline that includes such factors as crashworthiness, combat and repairability.

At the **Air Force Research Laboratory** at Wright-Patterson Air Force Base in Ohio, research conducted between January and September focused on **modeling debris propagation** physics and space system survivability from catastrophic breakups in multibody gravitational systems. One segment examined debris risks from spacecraft breakups in disposal and reconstitution parking orbits in **sun-Earth Lagrange-point orbits**, updating debris models for this regime for the first time since 2001. Another segment conducted large-scale **Monte Carlo simulations** to assess debris risks in **Martian orbits** for operational and disposed vehicles. Additionally, researchers tested the survivability of aerospace-grade aluminum honeycomb panels of varying thicknesses, firing projectiles from AFRL's cold gas gun at them to simulate high-speed impacts from debris fragments. Future research will focus on enhancing debris modeling fidelity in **cislunar space** and assessing debris risks to spacecraft operating in the **Earth-moon corridor**.

In the air domain, the **U.S. Air Force's 704th Test Group** in August conducted tests to quantify ullage ignition probabilities and overpressures under varying operational conditions, oxygen concentrations and ignition energy. They mapped the relationship between ballistic threat levels, ignition energy and overpressure, providing critical data for aircraft fuel system designers to reduce vulnerability while optimizing weight and cost. From February to August, graduate students at the **Air Force Institute of Technology**, AFIT, at Wright-Patterson completed research projects focused on reducing aircraft vulnerability to **kinetic and nonkinetic threats**. They analyzed results of fuel tank ballistic impact tests, measuring the time delay from impact to the first instance of fluid spurting out of the impact point — known as **shallow jet spurt**. This analysis considered the structural dynamics and material properties of the impacted fuel tank panel, and researchers found a correlation between the fluid-back natural frequency and the time delay for shallow jet spurt. This illustrated the importance of matching structural dynamic properties between the test article and the modeled aircraft of interest when designing future ballistic tests to mitigate fire hazards.

In May, **AFIT researchers with SURVICE Engineering Co.** of Virginia designed a **composite-copper component** to shield small unoccupied rotorcraft from **electromagnetic energy attacks**. The design incorporates heat transfer and electromagnetic shielding analyses to ensure functionality in contested airspace. Researchers also conducted **ballistic impact tests** on **composite armor panels** made from glass or aramid fibers, paired with different thermoplastic matrix options. The combination of aramid fibers and a high-density polyethylene matrix displayed the highest ballistic strength among the materials tested, highlighting the importance of material selection in armor design.

In March, researchers at the **Fraunhofer Institute for High-Speed Dynamics** in Germany achieved a milestone in **high-dynamic X-ray imaging**, creating the first continuous depiction of internal deformations of crash safety components not visible during high-speed events. This was possible with a new high-speed X-ray technology, capable of capturing 1,000 images per second. Traditionally, X-ray techniques have been applied statically to non-moving objects, while flash X-ray provided only limited images during high-speed events. They tested the new approach in a crash scenario, in which a deformable barrier collided with the side of a vehicle, while a custom-built **linear accelerator** by **Siemens** captured X-ray images at 1,000 Hertz. The 9-megaelectronvolt energy from the accelerator allows the X-ray to penetrate dense structures, requiring enhanced radiation protection. Laboratories at Fraunhofer were modified for X-ray and radiation safety to ensure controlled testing. This technology could enrich data collected during testing and improve the predictive capabilities of simulation methods. Future applications could include analyzing **thermal runaway processes** in battery packs for urban air mobility, as well as providing insights into internal processes during impact events like bird strikes on aircraft. ★

Contributors: *Air Force Lt. Col. Robert Bettinger, Air Force Maj. John Hansen, Colton Lapworth and Michael May*

Modernizing acquisition through digital engineering and AI

BY STEVEN H. DAM

The **Systems Engineering Technical Committee** supports efforts to define, develop and disseminate modern systems engineering practices.

▲ The USS Sea Hawk was among the vessels that participated in warfighting vignettes in San Diego Harbor during the XPONENTIAL trade show in April.

Steven Dam

The U.S. Department of Defense continued its decades-long effort to streamline the defense acquisition system. In January at AIAA's SciTech Forum, the **Department of the Air Force** held a workshop on **digital materiel management** aimed at streamlining through the application of digital engineering techniques. The goal is to create a consistent methodology that can be applied across the military services to quicken the adoption of new technologies.

The **Air Force** and **Space Force** followed up on this work in February, announcing a plan to make "sweeping changes to maintain superiority amid Great Power Competition," according to a press release. These changes, comprising 24 "near-term and longer-term initiatives," include the creation of an **Integrated Capabilities Office** "to lead capability development and resource prioritization to drive Department of the Air Force modernization investments" and the establishment of a **Space Futures Command** "that develops and validates concepts, conducts experimentation and wargames, and performs mission area design."

In the area of modeling and simulation, U.S. Reps. Bobby Scott (D-VA) and Jack Bergman (R-MI) in February called for increased utilization of those techniques to more rapidly update U.S. infrastructure. They presented separate keynotes at the National Training and Simulation Association's **Congressional M&S Leadership Summit**. Also during the summit, Dan Hettema, director of digital engineering, modeling and simulation within the Pentagon's Office of the Under Secretary of Defense for Research and Engineering, discussed the progress toward implementing **DoDI 5000.97**. This December 2023 directive described policies and procedures "for implementing and using digital engineering in the development and sustainment of defense systems."

In April, during the **XPONENTIAL 2024** trade show for autonomous vehicles and weapons systems, the U.S. Navy and various companies conducted a series of **"Pacific Pivot" outdoor demonstrations.** Among them, **Skydio** of California flew a drone to demonstrate airborne monitoring. Also part of these demonstrations was a warfighter vignette, in which a **SAAB CB90** ship acted as an attack vehicle that was detected by the surveillance systems and chased away by U.S. Coast Guard interceptors. The results of these demonstrations were captured in a **mission-based systems engineering tool** for further evaluation at later events.

In May, the Lifecycle Modeling Organization hosted its hybrid **MBSE-CON 2024** conference on the topic of how the development of new languages and capabilities plays into acquisition. During his keynote, Army executive Jeremy Lanman discussed how digital engineering is assisting with cutting costs at the Army Program Executive Office for Simulation, Training and Instrumentation.

Another technology of interest was artificial intelligence. In June, the Systems Engineering Resource Center hosted its third annual **Archimedes Initiative Workshop**, bringing together engineers from four U.S. and European research institutes to discuss modernizing systems engineering principles, practices and methodologies. The main discussion revolved around "Trustworthy AI," stemming from the concern that AI-generated results are often in error. Martin Stanley of the **U.S. National Institute of Standards and Technology** discussed how NIST's **AI 100-1** standard, released in 2023, can help organizations minimize the impacts of these risks.

In June, Defense Department officials discussed their efforts to develop a **digital acquisition "vision"** during the **Digital Engineering for Defense Summit**. There, the Test Resource Management Center announced it will develop a digital engineering infrastructure, as required by DoDI 5000.97. In September, the center with the Pentagon's Office of Developmental Test, Evaluation, and Assessments hosted **Hackathon 2.0** that brought together some 100 attendees to apply various digital engineering software to accelerate the development of systems. ★

Contributors: *Mathew O. French, Walter E. Hammond, Esma Karagoz and Marilee J. Wheaton*

Advancing the next generation of quiet flight

BY RUSSELL POWERS, IAN CLARK AND REDA MANKBADI

The **Aeroacoustics Technical Committee** addresses the noise produced by the motion of fluids and bodies in the atmosphere and the responses of humans and structures to this noise.

In February, the Connecticut-based **RTX Technology Research Center** in collaboration with **NASA's Langley Research Center** in Virginia tested an additively manufactured triply periodic **minimal surface acoustic liner** as part of **FAA's Center of Excellence for Alternative Jet Fuels and Environment Project 79** with **Pennsylvania State University**. The tests were conducted in the **Grazing Flow Impedance Tube** at NASA Langley in conditions representative of commercial aircraft engines, raising the prospects of incorporating these geometrically complex structures into the next generation of **turbofan engines**.

In April, **OptiNav Inc.** of Washington measured the noise produced by the **leading edge of a rotor blade** in ambient turbulence via a **digital microphone array** and **functional beamforming**. Researchers presented the results to the **NASA Urban Air Mobility Noise Working Group** to support the development of outdoor research measurement protocols and guidelines, particularly for understanding UAM vertiport noise.

Also in April, researchers at the **University of California, Irvine** conducted initial tests on a new technique for noise reduction from high-speed jets that relies on localized, parallel injection of secondary air. The intent is suppression of noise relevant to carrier deck crew by reducing the efficiency by which **turbulent eddies** generate noise. Out of nine tested configurations, the best configuration achieved a reduction of 3.4 A-weight decibels. The experiments are to continue with near-field noise measurements, including reflections from simulated surfaces of the carrier deck.

The **30th AIAA/CEAS Aeroacoustics Conference** was held at the beginning of June in Rome and featured the most total presented papers ever at an AIAA/CEAS aeroacoustics event. During the conference, the **2024 Aeroacoustics Award** was presented to Krishnamurthy Viswanathan for his experiments on **aircraft engine noise** and his development of **noise reduction concepts for turbofans**.

In June, researchers at **NASA Langley** and **NASA's Ames Research Center** in California completed a four-year technical challenge on assessment of **UAM operational fleet noise**. This challenge was under the **NASA Revolutionary Vertical Lift Technology project** and supports the NASA Aeronautics Research Mission Directorate vision for "safe, quiet, and affordable vertical lift vehicles." Key accomplishments include the development of community noise modeling methods with **FAA's Aviation Environmental Design Tool** and psychoacoustic annoyance models that account for vehicle sound quality and ambient environmental noise.

In July, researchers from the **U.S. Army** and **NASA's Revolutionary Vertical Lift Technology project** completed a comprehensive acoustic flight test campaign at **Sierra Army Depot** in California. Ground-based microphone arrays recorded noise from an instrumented MD-530 helicopter to guide future UAM flight test techniques and characterize the noise generated by a novel main rotor blade set. The test vehicle flew 11 sorties to meet all test objectives, which included investigating a new **snapshot array design**, increasing flight test efficiency, making **phased array measurements** for rotating source separation and localization, ground board sizing studies, and increasing the overall experience of the flight test team.

In April, some 60 high school students from Ohio visited **NASA's Glenn Research Center** as part of the culminating event of the **Acoustic Damping Capstone Project**. Thousands of middle school and high school students nationwide discovered NASA's aviation noise reduction research via the project, which education program specialists and researchers at NASA Glenn created in 2016. Four of the eight universities in **NASA's Minority University Research and Education Project's Aerospace Academy** also participated. The **University of Texas at El Paso** constructed 75 simplified normal incidence impedance tubes, reaching 1,200 students. ★

Contributors: *Robert Dougherty, L. Danielle Koch, Jeffrey Mendoza, Dimitri Papamoschou, Kyle Pascioni, Stephen Rizzi and James Stephenson*

◀ In this split image, an instrumented MD-530 helicopter flies over the NASA Wireless Acoustic Measurement System at Sierra Army Depot in California. In this July campaign, 11 sorties were flown to capture recordings of rotor noise and other metrics that researchers plan to reference when creating flight test plans for future urban air mobility aircraft.

U.S. Army/NASA

Advances in high-speed optical diagnostics help characterize airflows from subsonic to hypersonic speeds

BY TOM JENKINS

The **Aerodynamic Measurement Technology Technical Committee** advances measurement technology for ground facilities and aircraft in flight.

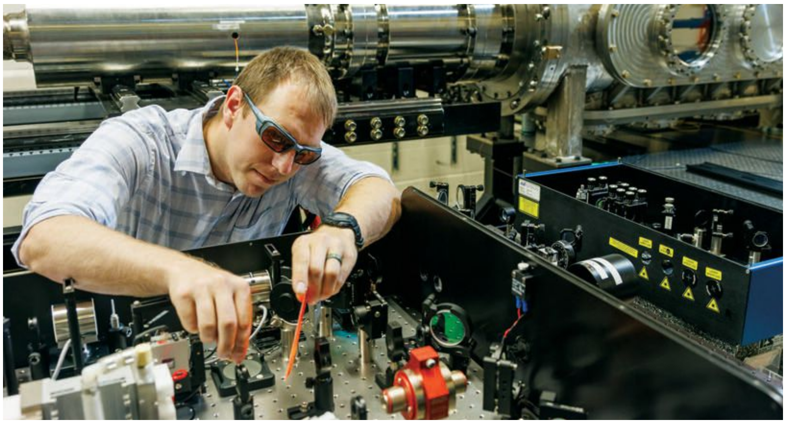
In January, engineers at **Sandia National Laboratories** in New Mexico characterized the flow of their free-piston **Hypersonic Shock Tunnel** via novel **laser diagnostics**. The tunnel, which was first operated in 2021, uses noncontact shock heating to generate high-temperature gas supplied to a nozzle. This process dissociates the oxygen and nitrogen molecules in the air to form other atomic and molecular compounds, including nitric oxide. Rapid expansion through the nozzle produces flow in **thermochemical nonequilibrium** through processes that are not well understood. The engineers developed a nitrogen and oxygen temperature measurement technique based on coherent **anti-Stokes Raman scattering** that can operate at a 100-kilohertz rate. They measured the flow velocity simultaneously via nitric oxide molecular tagging velocimetry. Finally, they measured nitric oxide temperature via **laser absorption spectroscopy**, a technique developed in conjunction with **Purdue University** of Indiana. The measurements captured the temporal evolution of the flow and revealed pronounced thermal nonequilibrium, with each molecular species having a higher vibrational temperature than rotational temperature. This was the most extensive characterization of shock tunnel flow ever performed, and researchers are referencing the measurements in their creation of models in **hypersonic computational fluid dynamics codes**.

Also in January, researchers at the **Boeing/Air Force Office of Scientific Research Mach-6 Quiet Tunnel** at Purdue demonstrated **two-photon laser-induced fluorescence measurements** of carbon monoxide at rates faster than 1 kHz. They pushed the state-of-the-art two orders of magnitude to 100 kHz with a burst-mode laser and optical parametric oscillator at a wavelength of 230.1 nanometers, suitable for use in hypersonic wind tunnels. The two-photon carbon monoxide technique allowed for advances in coupled measurements of ablation products and gas mixing in boundary layers and wakes.

In July, researchers at the **University of Toronto** used an array of **micro-electromechanical-systems-based synthetic jet actuators** to reattach separated flow on a stalled wing, based on a **NACA0025 airfoil** at a Reynolds number of 100,000 and 10-degree angle of attack. Smoke visualizations highlighted the **spanwise control effects** on the shear layer at the trailing edge. With the high-speed, multiple-view visualization, they identified that **lower duty-cycle synthetic flow control** was capable of keeping the flow attached. An optimum voltage and duty cycle for the actuators led to full flow reattachment, demonstrated by a thin, steady shear layer and a stable smoke pattern centered about the midspan. The visualizations illustrated the effects of using low-duty cycles for power-efficient synthetic jet flow control over wing surfaces.

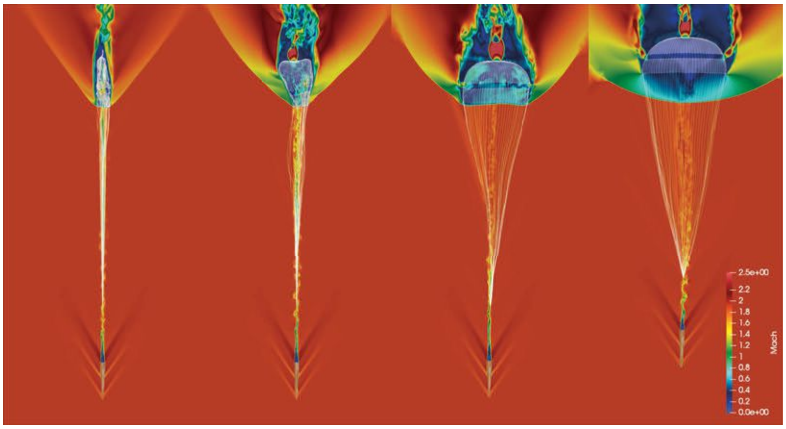
In May, California-based **MetroLaser Inc.** delivered several high-speed- and ultrahigh-speed-focusing schlieren systems for the **Von Karman Gas Dynamics Facility Wind Tunnels** at the **Arnold Engineering Development Complex** in Tennessee. In June, these turnkey systems delivered high-quality images at a focal plane and quasi-planar images at framing rates of 10 kHz, 20 kHz and 100 kHz. Further, these systems used short-pulsed light sources with pulse durations of 50 nanoseconds to 2 microseconds, thereby yielding images that can be considered frozen based on Taylor's Hypothesis and are therefore representative of supersonic and hypersonic flow regimes. For time-resolved images of relevance to hypersonic dynamics, similar 1 MHz to 5 MHz systems are also available. In August, **MetroLaser** operated several of its ultrahigh-speed holography systems at 100-kHz, 1-MHz and 5-MHz measurement rates, partnering with researchers at **Texas A&M University** to interrogate several hypervelocity impact situations pertaining to projectile-material impacts and projectile-hydrometeor impacts in Texas A&M's two-stage light gas gun. Also in August, **MetroLaser** teamed with the **University of Michigan** to develop and build a state-of-the-art, ultrahigh-speed sensor using **two-color heterodyne interferometry**, which is planned for future megahertz-rate electron number density measurements in the **Electric Arc Shock Tube Facility** at **NASA's Ames Research Center** in California. ★

Contributors: *Pierre Sullivan and Justin Wagner*



▼ Technician Elijah Jans prepares the pulse-burst laser at Sandia National Laboratories in New Mexico for January tests to characterize the flow in the laboratory's Hypersonic Shock Tunnel.

Sandia National Laboratories



From micro-vortex generators to supersonic parachute dynamics, researchers glean deeper insights

BY JENNIFER ABRAS AND MEHDI GHOREYSHI

The **Applied Aerodynamics Technical Committee** emphasizes the development, application and evaluation of concepts and methods using theories, wind tunnel experiments and flight tests.

▲ This simulation of the Jet Propulsion Laboratory's ASPIRE SR03 supersonic parachute was created by researchers from Stanford University, JPL and Stevens Institute of Technology in New Jersey. From left to right, the simulation depicts the amount of inflation at 0.1, 0.2, 0.3 and 0.5 seconds into flight.

Stanford University/Faisal As'ad

In January, researchers at the **Birla Institute of Technology and Science, Pilani** in Dubai reported on their study of the effects of perforation on the characteristics of the downstream vortex of a micro-vortex generator, or MVG, using **Reynolds-Averaged Navier-Stokes modeling**. Such generators can enhance aircraft performance by introducing vortices in the boundary layer to delay stall. The computational study investigated the effect of placing a single circular and square perforation at different locations on the MVG, which was mounted on a flat plate. The generator was then placed inside a turbulent boundary layer at a Reynolds number of 16,293, based on its height and free-stream velocity. The results indicated that the MVG vortex is most effective when the perforation is at the center and lower side of the MVG. The vortex strength for the MVG with this perforation location was found to be much higher than that of an MVG without perforation.

In June, **researchers from France, Germany, Italy, Sweden, Turkey, the U.K. and the U.S.** reported on their multiyear study into the use of **computational fluid dynamics** for predicting **vortex-dominated airflows** generated by a generic missile airframe. Conducted under AVT-390, a NATO Science and Technology Organization research task group, the study consisted of extensive, systematic comparisons of **Reynolds-Averaged Navier-Stokes** and **scale-resolving computations** with data acquired from multiple wind tunnel tests, including pressure-sensitive paint and particle image velocimetry measurements. The researchers identified several residual numerical challenges in simulating vortices that could be applied to improving the stability and control analyses of missile configurations.

In June, **NASA** tested the **Adaptable Distributed Electric Propulsion Testbed, or ADEPT**, wing in the 12-Foot Low-Speed Tunnel at NASA's Langley Research Center in Virginia. The tests were conducted under **SUSAN, the Subsonic Single Aft Engine Electrofan aircraft project**, in which NASA is assessing electric propulsion technologies that could reduce carbon emissions for commercial transport aircraft. With ADEPT, researchers can rapidly test electric propulsors along a wing to study propulsion-airframe interactions and propulsor-propulsor interactions for distributed electric propulsion designs. In the Langley wind tunnel test, they compared the propulsion-airframe interactions characteristics for up to five electric ducted fans placed in various positions across the wing, and studied how distributed electric propulsion could be leveraged for high-lift and lateral-directional control. The experiment indicated ideal fan placement for the SUSAN concept and provided experimental data to compare with results from computational methods.

In July, a joint team of researchers from **Stanford University, NASA's Jet Propulsion Laboratory and Stevens Institute of Technology** tackled the challenging task of simulating **supersonic parachute inflation dynamics**. These **fluid-structure interaction simulations** involve capturing heterogeneous flow features at different scales, such as shocks, under-expanded jets, turbulent wakes and thin boundary layers. These complex flow features interact with the nonlinear porous woven fabric canopy and thin braided suspension lines of a parachute, which can be computationally expensive and challenging to model. This research focused on validating the multi-physics simulation environment, **AERO Suite**, in a simulation of supersonic parachute inflation dynamics by establishing sensitivity of the simulation accuracy to different choices. They simulated an inflation of **JPL's ASPIRE SR03 supersonic parachute** and compared several quantities of interest to the flight data, identifying several areas for further analysis and improvement. Their goal was to establish best practices for numerical simulations of supersonic parachute inflation dynamics and to advance the potential role of computational fluid-structure interaction in the design and evaluation processes of inflatable aerodynamic decelerator systems. ★

Contributors: *Faisal As'ad, Shashank Khurana, Magnus Tormalm and Rose Weinstein*

Moon shadows and lunar far side samples headline the year

BY JAMES D. THORNE

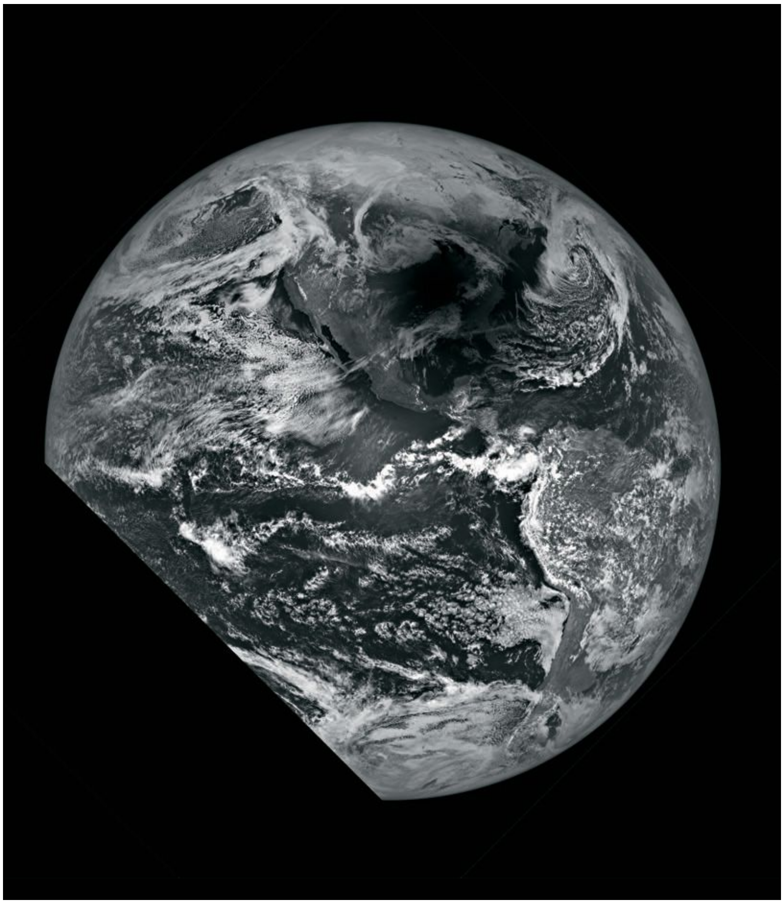
The **Astrodynamics Technical Committee** advances the science of trajectory determination, prediction and adjustment as well as spacecraft navigation and attitude determination.

In April, millions of people around the world traveled to North America to witness the **solar eclipse**, visible on April 8 in its totality across a slice of eastern Canada, the United States and central Mexico. In orbit, NASA said that the astronauts on the **International Space Station** had several opportunities to observe the eclipse. Scientifically, a total eclipse of the sun allows for studies of the sun's corona and its gravitational lensing effect on the starlight coming from behind it.

A natural alignment of three celestial bodies such as the sun, moon and Earth, known as a syzygy, can take decades to repeat since they do not lie in the same plane except on rare occasions, so scientists have devised multiple ways to block the sun's rays and form an artificial eclipse. For example, **NASA's New Horizons** space probe in 2015 used Pluto to block the sun so that its instruments could detect the molecules that comprised the dwarf planet's tenuous atmosphere. In February, the **European Space Agency** completed final integration of its **Proba-3** satellites, which will use yet another technique to observe the sun's corona: **occulters**, circular lenses installed on space-based telescopes to block the sun's photons from reaching their detectors. However, placing an occulter too close to a telescope increases the potential for **light diffraction**, in which sunlight spills over the edge of the lens and blocks out fainter signals. So ESA plans to fly the two Proba-3 satellites in formation — one spacecraft with the occulter, the other with a coronagraph telescope. After their launch aboard an Indian rocket, scheduled for December, the satellites are to fly 144 meters apart in similar elliptic orbits, thus creating an eclipse for roughly six hours near each apogee, when the occulter spacecraft casts a shadow on the spacecraft with the coronagraph. Because of these slightly different orbits, the spacecraft will require small maneuvers to maintain the proper alignment to study the sun as it forms repeatable eclipses.

In June, **China** retrieved the first samples from the far side of the moon and returned them to Earth. This **Chang'e-6** mission began in March with the launch of the **Queqiao-2 relay** satellite. The moon always keeps one face away from Earth due to tidal locking, so some form of satellite is required to relay communications to any lander touching down on the far side. Queqiao was placed in a **highly elliptical frozen orbit**, meaning one that naturally maintains its orientation due to the moon's uneven gravity field combined with perturbations from the Earth's gravity. Then in May, the Chang'e-6 spacecraft comprised of a lander and orbiter, among other components, was launched toward the moon. The lander and its ascent stage in June touched down in the **South Pole-Atiken Basin**, an ancient lava field on the lunar far side, where the lander drilled into the surface and picked up regolith with its robotic arm. Nearly 2,000 grams were collected and placed into a return capsule, which touched down under parachutes in Mongolia in late June.

Chang'e-6 marks the second time China has landed a robotic craft on the far side of the moon; the first lander, Chang'e-4, touched down in 2019. The 12 Apollo astronauts who visited the lunar surface landed generally in the equatorial region of the lunar near side, although there were proposals to visit the far side during the planned Apollo 20 mission before the Nixon administration canceled that landing and two others in the early 1970s. ★



▼ This composite of the April solar eclipse was created from images taken by the Lunar Reconnaissance Orbiter. The spacecraft was rotated to capture the moon's shadow as it crossed North America.

NASA

Sounding rocket launches, new public models and data highlight progress

BY LINDA HABASH KRAUSE

The **Atmospheric and Space Environments Technical Committee** encourages the exchange of information about the interactions between aerospace systems and their surroundings.

In August, researchers at the **Missouri University of Science and Technology** completed setup of their replica of a low-Earth orbit plasma environment. Housed within a gas chamber of the university's **Gas and Plasma Dynamics Laboratory**, this setup was funded by the **National Science Foundation, NASA's Lunar Surface Technology Research program and the Air Force Office of Scientific Research**, with additional financial support from **NASA's Missouri Space Grant Consortium**. The chamber allows for precise measurements of plasma densities and temperatures comparable to actual space conditions.

Several missions observed this year's solar phenomena. In early April, NASA launched three **sounding rockets** from **Wallops Island** in Virginia as part of the **Atmospheric Perturbations Around Eclipse Path 2 mission** to explore the effects of solar eclipses on ionospheric plasma and thermospheric cooling. These rockets, launched in succession 45 minutes apart, measured "charged and neutral particle density and surrounding electric and magnetic fields" before, during and after the April 8 eclipse, according to a news release.

Later that month, the **Focusing Optics X-ray Solar Imager 4 (FOXSI-4) and the High-Resolution Coronal Imager (Hi-C) Flare sounding rockets** were launched from the Poker Flat Research Range in Alaska. FOXSI-4, equipped with specialized optical modules and detectors, observed solar X-rays during an **M-class solar flare** detected by **NOAA's Geostationary Operational Environmental Satellites**. Simultaneously, Hi-C Flare's low-noise cameras, built by **NASA's Marshall Space Flight Center** in Alabama, captured detailed observations during the flare. This coordinated effort provided unprecedented multi-mission observations of solar flare activity and the extreme energies involved in these phenomena.

In July, the **Marshall Grazing Incidence X-ray Spectrometer 2 sounding rocket** was launched to investigate how solar magnetic energy converts to heat. Researchers targeted the sun's corona with **X-ray spectroscopy**. In September, the **Full-sun Ultraviolet Rocket Spectrometer sounding rocket** was launched to collect the first high-resolution far-ultraviolet spectrum of the entire sun. These missions, combined with data from **NASA's Interface Region Imaging Spectrograph satellite**, provided greater detail about solar phenomena and their impacts on Earth's technological systems.

Several models were updated and released through **NASA's Community Coordinated Modeling Center**. In July, the **WideBand ionospheric scintillation MODel v17**, which predicts ionospheric scintillation effects, was made available through the CCMC Instant-Run service. **MAGE model suite v0.75** was released in April, so researchers could study the solar impact on Earth's magnetosphere, ionosphere and ring current. The **Horizontal Wind Model**, released in March, allows custom conditions to be set for upper thermosphere wind simulations. **CORHEL-CME model v1.0**, released in February, allows researchers to simulate coronal mass ejections in realistic environments. Also released in February was the **DTM 2020** model, which describes the thermosphere's temperature, density and composition.

In June, **NOAA's National Centers for Environmental Information** announced the end of its ionosonde data program, concluding a decade of near real-time ionospheric data collection. Observations from some 100 ground-based ionosondes will remain accessible, providing long-term archives for space weather research.

In May, NASA retired its **DC-8** aircraft, a versatile airborne platform for atmospheric, climate and space science research. After 37 years of service, the plane will now be used for training future aircraft technicians at Idaho State University.

In January, **NASA's Ingenuity Mars helicopter** completed its 72nd and final flight. One of the helicopter's rotor blades was damaged upon landing. Ingenuity made history in 2021 as the first aircraft to achieve powered flight on another planet. Over the course of its mission, it provided information on flight performance, Martian surface terrain and atmospheric conditions. ★

Contributors: *Emmanuel Kofi Asuako Wie-Addo, Nelson Green and Daoru Han*

Researchers at the Missouri University of Science and Technology modified this vacuum chamber in the Gas and Plasma Dynamics Laboratory to simulate a plasma environment in low-Earth orbit.

Missouri University of Science and Technology

New takeoff and landing capabilities headline a momentous year

BY SOUMYO DUTTA, BRADFORD ROBERTSON AND CRAIG WOOLSEY

The **Atmospheric Flight Mechanics Technical Committee** addresses the aerodynamic performance, trajectories and attitude dynamics of aircraft, spacecraft, boosters and entry vehicles.

▲ Varda Space Industries' W-1 capsule reentered in February, touching down under parachutes in northern Utah. This was the first flight for the California startup, which aims to manufacture various materials in orbit aboard its W-series capsules.

Varda Space Industries/John Kraus

In February, **Varda Space Industries** of California landed its first reentry capsule, which carried a payload that manufactured pharmaceutical ingredients on orbit. Varda is among the companies aiming to establish a market of in-space manufacturing and returning materials to Earth. During reentry, the capsule was shielded by **Conformal Phenolic Impregnated Carbon Ablator**, a thermal protective coating that is among the latest heatshield materials developed by NASA. This was the first time the material went to space.

Another reentry milestone came in June, during SpaceX's fourth flight of a **Starship-Super Heavy**. After sending the **Starship** upper stage toward orbit, the **Super Heavy** booster splashed down in the Gulf of Mexico. Starship continued, surviving peak heat loads through the atmosphere for the first time and landing softly in the Indian Ocean. SpaceX livestreamed video of Starship maneuvering while encountering plasma. In the fifth flight, a Super Heavy was captured by tower chopsticks for the first time, and on the sixth flight, a Starship restarted an engine in space for the first time.

In its pursuit of faciliating the return of overland civil supersonic flight, **NASA** continued to prepare for the first flight of its **X-59** demonstrator. In May, the aircraft passed its **flight readiness review**, in which an independent review board studied the plan to ensure public and staff safety during testing. This was the first step toward approving the aircraft for flight tests, in which NASA and prime contractor **Lockheed Martin** plan to demonstrate how X-59's design reduces the **sonic boom** to a "thump."

The burgeoning community of **advanced air mobility** continued to push its boundaries. In May, electric aircraft manufacturer **Electra** of Virginia announced its **hybrid-electric demonstrator** had achieved its first **ultra-short takeoff and landing**. In these piloted test flights, the aircraft operated from a space shorter than 91 meters.

Also in the novel takeoff-and-landing arena, **Lockheed Martin** in May said that it subsidiary **Sikorsky** was flight testing its **rotor blown wing concept** under **DARPA's ANCILLARY** program, short for **Advanced Aircraft Infrastructure-Less Launch and Recovery**. The term "rotor blown wing" refers to "the constant airflow from the proprotor wash across the wing," Lockheed Martin said in a press release, which reduces drag during vertical takeoff and transition to horizontal flight. Flight testing of an electric proof-of-concept vehicle has focused on verifying the vehicle's ability to take off and land vertically, as well as cruise.

With advances in takeoff and landing capabilities, there may be additional avenues for seamless integration between machines and humans. One such venue is the **X-62A VISTA,** a modified F-16 trainer that **DARPA** and the **Air Force Test Pilot School** have flown, controlled by artificial intelligence algorithms. In May, **Air Force Secretary Frank Kendall** flew in the front seat of the aircraft, with a safety pilot in the backseat, while AI piloted the aircraft. This was another step toward the integration of AI in fighter planes.

In the area of **wind tunnel testing**, NASA made progress in the construction of a new facility, the **Flight Dynamics Research Facility** at **NASA's Langley Research Center** in Virginia. This is the first major wind tunnel built by NASA since the opening of the **National Transonic Facility** in the early 1980s. FDRF is a large, subsonic tunnel with a vertical test section, which will be used to conduct all aspects of flight dynamics research, from **basic stability and controllability** to **entry vehicle free-fall dynamic stability** and **aircraft spin** and **spin-recovery characterization**. Planned to open in 2025, FDRF is to replace two Langley tunnels that have been operating for some 80 years. ★

Contributors: *Wendy Okolo and Benjamin Simmons*

Measuring, simulating, predicting and controlling fluid motion

BY EYLUL BILGIN AND PEDRO PAREDES

The **Fluid Dynamics Technical Committee** focuses on the behaviors of liquids and gases in motion and how those behaviors can be harnessed in aerospace systems.

In March, **Purdue University** researchers in Indiana completed a test campaign in which they raised the **maximum quiet Reynolds number** in the Boeing/Air Force Office of Scientific Research Mach 6 Quiet Tunnel to 21×10^6 m^{-1}. This is a world record for hypersonic low-disturbance tunnels, up from 15×10^6 m^{-1} in 2022. This breakthrough enables the study of hypersonic turbulence under low-disturbance conditions, which the team demonstrated by observing natural transition on boundary layer transition geometry, with transition Reynolds numbers similar to those seen in the BOLT-II flight test in 2022.

In conventional hypersonic wind tunnels, tunnel noise is dominated by acoustic radiation from **turbulent nozzle-wall boundary layers**, which can directly influence the **boundary layer transition, BLT,** over the model in the test section. Relating the noisy tunnel measurements of BLT to that in flight has long been difficult, but direct numerical simulations are now offering new insights into this problem. In January, researchers from the **Ohio State University, Sandia National Laboratory** in New Mexico, **National Institute of Aerospace** in Virginia and **NASA Langley Research Center** in Virginia completed a DNS of Mach 8 flow over a sharp cone in the axisymmetric nozzle of the **Sandia HWT-8** facility. The DNS realized all the stages of the transition to turbulence caused by tunnel noise, while capturing the relevant physics. Direct comparison with experiments at the Sandia HWT-8 confirmed the accuracy of the numerical procedure for imposing a "tunnel-noise" model to mimic the disturbance environment in a conventional hypersonic wind tunnel, thereby established the foundation for "virtual'' testing of the hypersonic BLT in a noisy digital wind tunnel.

▼ DARPA in 2025 plans to fly the X-65 to test the concept of active flow control. X-65 would maneuver by manipulating the surrounding airflow with active flow control actuators, rather than external moving surfaces like those on other aircraft.

DARPA

During AIAA's Aviation Forum in late July and early August, researchers from the **University of Maryland** presented the results of their investigations of the flow physics of droplet impingement at hypersonic speeds. They presented newly developed scaling relationships that allow for the collapse of integral forces generated during **high-speed droplet impingement**. These scaling laws can be used to establish reduced order models applicable for the assessment of hypersonic vehicles flying through adverse weather conditions. The researchers also presented a new simulation approach that captures the transition between continuum and dispersed phase behavior of water. During impingement, water droplets break into sub-droplets, altering acoustic wave behavior and spray dynamics. This new simulation better captures droplet dynamics during aerobreakup. Other applications of this simulation approach include, for example, high-speed water impact and underwater explosions.

In August, **MIT** researchers presented a closure model for **computation fluid dynamics** that improves predictions of high-speed flows for entry, descent and landing vehicles. Unlike previous models, the building-block-flow model uses neural networks and combines fluid physics with machine learning to address a broader range of flow regimes. The model accurately predicted turbulence, flow separation, compressibility and heat transfer in rough surfaces. It outperforms earlier models, as demonstrated in both channel flow tests and realistic entry, descent and landing scenarios.

In January, **DARPA** selected **Aurora Flight Sciences** of Virginia to build a full-scale X-plane, designated **X-65**, to demonstrate the viability of primary flight control via active flow control actuators. Plans call for the X-65 to have two sets of control actuators: "traditional flaps and rudders, as well as AFC [active flow control] effectors embedded across all the lifting surfaces," according to a DARPA press release. "The plane's performance with traditional control surfaces will serve as a baseline; successive tests will selectively lock down moving surfaces, using AFC effectors instead." The unoccupied X-65 will have a 9-meter wingspan and be able to fly at speeds up to Mach 0.7. Flight testing is targeted for 2025. ★

Contributors: *Christoph Brehm, Lian Duan, Joseph S. Jewell, Adrian Lozano-Duran and Martiqua Post*

Testing spans flow speed extremes

BY BRAD RAFFERTY

The **Ground Testing Technical Committee** focuses on evaluating aircraft, launch vehicles, spacecraft, structures and engines in wind tunnels and other facilities

From December 2023 through May, the 5.2%-scale **High Lift Common Research Model semispan model** was tested in the **National Transonic Facility** at **NASA's Langley Research Center** in Virginia. Researchers tested configurations for landing, takeoff and icing conditions between Mach 0.2 and 0.35, and chord Reynolds numbers between 1,800,000 and 30,000,000. With test results from Common Research Models, researchers compare different wind tunnels, improve computational fluid dynamics and increase wind tunnel testing knowledge.

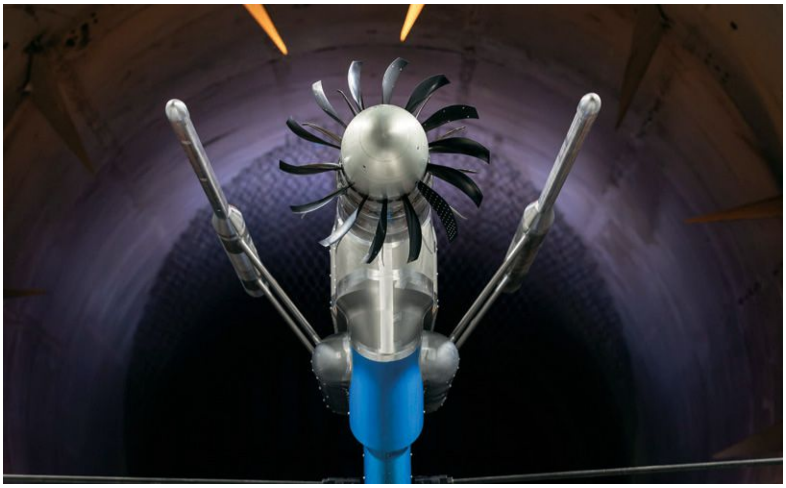
In March, researchers integrated the **Triple Annular Research Swirler** model jet engine combustor, which features **swirl-stabilized combustion** and **lean-direct injection** of liquid fuels, into the atmospheric combustion facility at **Lund University** in Sweden. Commissioning was ongoing as of November, and bioderived fuel testing began in September to support the production and use of **sustainable fuels** for **stationary gas turbines** and **jet engines**.

In September, **Ohio State University** reintroduced its **Large Area Reflected Shock tunnel** for experimental hypersonics. The tunnel has a 114-centimeter-diameter nozzle and can generate clean air test conditions at flight enthalpies over Mach 8, with cold flow runs possible over Mach 10.

RUAG of Switzerland implemented a new test rig for propellers approximately 2 meters in diameter in its **Large Wind Tunnel** in Emmen. It delivers up to 400 kilowatts at a maximum speed of 2,700 revolutions per minute and yaws within a 110-degree range. There, **Archer Aviation** of California completed an extensive wind tunnel campaign, in which propellers for its **Midnight air taxis** were tested throughout their expected flight envelope.

▼ Safran Aircraft Engines in January began wind tunnel tests of its ECOENGInE demonstrator to test technologies for a future Open Fan engine in development to power the next generation of passenger airliners. Safran says the open-fan design could reduce fuel burn and carbon dioxide emissions by 20%.

Safran Aircraft Engines



In January, **Safran Aircraft Engines** said it had begun a 200-hour test campaign of the **ECOENGInE**, a 1:5-scale demonstrator of its planned **Open Fan engine**, at the French national aerospace research center's wind tunnel in Modane, France. With the Open Fan design, Safran is targeting a 20% reduction of **fuel burn** and **carbon dioxide emissions** for the next generation of single-aisle commercial jets.

In June, **Wisk Aero** of California performed testing at **Boeing's Vertical/Short Take-Off and Landing Wind Tunnel** in Pennsylvania to characterize the propellers for it sixth-generation air taxi design. Researchers measured thrust and torque, along with strain on blades and pitch links, to calibrate simulation and performance models.

In June, **Lilium** of Munich exercised its electric engines up to maximum thrust on its dual-engine propulsion unit test bench, to help verify safety of flight of its planned Lilium Jet aircraft. The company and its subsidiaries filed for insolvency in late October and early November, but Lilium says that construction of the first two prototypes continues.

At **Texas A&M University**, researchers planned to complete by the end of the year the first phase of the **Ballistics Aero-optics and Materials Range**, which includes a two-stage light-gas gun with a 10.2-centimeter diameter launch tube, a 30.5-meter free-flight range, a 257-meter-long guided flight range and a 419-meter-long directed energy range.

From February to March, **NASA's Stennis Space Center** in Mississippi and **Amentum** of Virginia completed installation of the **Sea-Level Plume Management System** and in October an **Interstage Simulator** at the Thad Cochran Test Stand. The equipment is to help qualify the Exploration Upper Stage, a more powerful second stage for the Block 1B variant of **NASA's Space Launch System** rockets.

At **CFD Research** in Alabama, researchers demonstrated tenths of pound per second mass flow rates of clean air at **hypersonic enthalpies** using nitrous oxide decomposition in the prototype wind tunnel, Puff. This tunnel and a larger version in development aim to introduce unprecedented ground testing capabilities in clean air matched to hypersonic flight enthalpies over mission-length durations and trajectories. ★

Contributors: *Peter Aschwanden, Kyle Bokariza, Bora O. Cakir, Madeleine Finnegan, Roger Herdy, Sarah Langston, Jesse Little, Tyler McElroy, Melissa Rivers, Nathan Tichenor and Courtney Winski*

Enabling groundbreaking missions

BY KERRI B. PHILLIPS

The **Guidance, Navigation and Control Technical Committee** advances techniques, devices and systems for guiding and commanding flight vehicles.

▲ Air Force Secretary Frank Kendall rode in the X-62 VISTA aircraft (foreground) in early May, accompanied by a safety pilot. The aircraft was controlled by artificial intelligence algorithms.

U.S. Air Force/Richard Gonzales

READ THE APPRECIATION

CAROLINA RESTREPO, NASA LEADER IN AUTONOMOUS PRECISION-LANDING TECHNOLOGIES

It was a year of advances for guidance, navigation and control for space, missile and aircraft applications.

In October, **SpaceX** completed the fifth test flight of a **Starship-Super Heavy**. In an unprecedented feat, the Super Heavy booster navigated back to the launchpad and was caught by two **mechanical arms** as the engines shut down, bringing SpaceX another step closer to rapid reusability. The Starship upper stage splashed down in the Indian Ocean.

In April, Japan's **Mitsubishi Corp.** joined **Starlab Space**, a joint venture of **Airbus** and **Voyager Space** of Colorado to develop and privately operate a station in low-Earth orbit. Starlab is among the potential successors to the **International Space Station**.

In October, **NASA's Europa Clipper** spacecraft was launched toward Jupiter's moon **Europa**, which it is scheduled to reach in 2030. Also that month, the **European Space Agency** launched the **Hera** spacecraft, a follow up to NASA's 2022 **Double Asteroid Redirection Test**, which impacted a spacecraft into a moonlet of the asteroid Didymos and altered its orbit. Hera will navigate to the double system and collect observations to help determine if such a **kinetic impact** is a feasible method for planetary defense.

There were several noteworthy activities in applying **artificial intelligence**. In April, **Klepsydra Technologies** of Switzerland announced an agreement to fly its AI models on **Firefly Aerospace's Elytra** spacecraft to demonstrate **onboard decision-making and autonomous navigation**. During the flight, Klepsydra's models "will process sensor data onboard," then relay the spacecraft's GNC information to Earth, according to a press release.

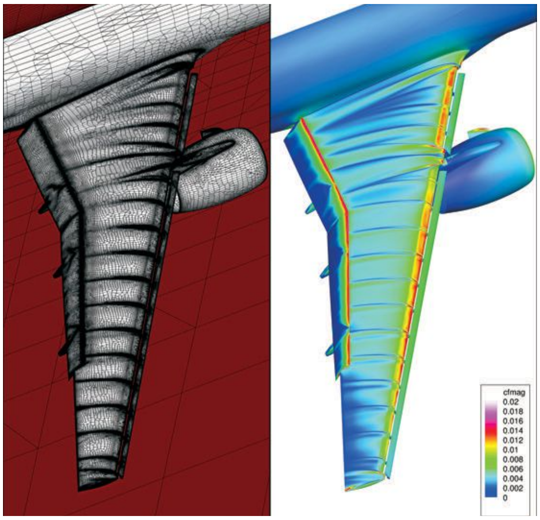
Also in April, the **U.S. Air Force** announced that **AI agents** had piloted the **X-62A VISTA**, a modified F-16 trainer, in a series of dogfighting exercises against a human-piloted F-16 at Edwards Air Force Base in California. The goal of the flights, conducted under **DARPA's Air Combat Evolution program**, was to train and test algorithms for eventual use with future uncrewed aircraft. Similarly, the **Air Force's Collaborative Combat Aircraft program** continued pushing to rapidly design and deploy large numbers of autonomous uncrewed aircraft to team with crewed fighter aircraft squadrons as part of the **Next Generation Air Dominance program**. The Air Force in April selected California-based **Anduril** and **General Atomics Aeronautical Systems** to further prototype and fly their drone designs.

In March, the **Air Force** conducted the final test flight of the **Air-Launched Rapid Response Weapon**. A spokesperson said that this test "focused on the ARRW's end-to-end performance" and that "the Air Force gained valuable insights into the capabilities of this new, cutting-edge technology." Also that month, **Stratolaunch** completed the first powered flight with a **Talon-A**, its reusable hypersonic test vehicle. **Draper** developed the GNC flight software for TA-1's autonomous operation, one of the primary objectives for the flight.

Uncrewed aerial systems and counter-UAS concepts have exploded in use in both the Russia-Ukraine and Israel-Hamas wars. Both the use of drones and methods to counter them are undergoing rapid adaptation, with GPS spoofing to disrupt navigation and radio-frequency jamming to break communications links being reported. As C-UAS technologies continue to evolve, researchers will create new solutions to counter the counter.

In advanced air mobility news, **Eve Air Mobility** of Brazil in January selected **Honeywell** to develop guidance and navigation systems for its planned electric air taxi, scheduled to begin passenger service in 2026. Also in January, **Xwing** and **AFWERX** completed an **autonomous logistics demonstration** with a **Cessna 208B** turboprop, in which pilots monitored the flight with **Xwing's Superpilot software**. In June, air taxi developer **Joby Aviation** of California acquired the autonomy division of Xwing for future uncrewed operations of its aircraft. ★

Contributor: *Omkar Halbe*



▲ The mesh overlaying the wing on the left was generated by Helden Aerospace's HeldenMesh software, and the computational fluid dynamics image on the right depicts areas of skin friction. Areas of lower friction are represented in blue, and areas of higher friction in red.

Helden Aerospace

Powerful new capabilities emerge across the community

BY DAVID MCDANIEL AND CIARÁN O'CONNOR

The **Meshing, Visualization and Computational Environments Technical Committee** explores the application of computer science to preprocessing, post-processing and infrastructure in support of computational simulation in the aerospace community.

Organizations across industry and government provided powerful new capabilities and streamlined workflows.

In August, **Intelligent Light** of New Jersey delivered its **IntelliTwin** and **Kombyne** tools to the **U.S. Air Force Research Laboratory** and **U.S. Air Force Academy**. Developed under a Direct-to-Phase II Small Business Innovative Research project, the software provides optimized and streamlined simulation and postprocessing workflows, which allows users more time for learning and innovating. The web-based point-and-click interface allows engineers to rapidly set up multiple cases, execute them on remote **high-performance computing systems**, and monitor and visualize the results in real time. The workflow has already made an impact on the computational aerodynamics curriculum at the academy, allowing for deeper discussions and what-if analyses in projects conducted throughout the semester.

The workflow to generate structured grid systems for complex geometries is notorioudrsly time-consuming. In June, researchers at **NASA's Ames Research Center** in California demonstrated for the first time the full automation of **structured grid preprocessing**, spanning the workflow from input geometry to the start of the flow solution computation. The automated steps included surface mesh generation, volume mesh generation, domain connectivity and solver input deck creation. As a result, the meshing turnaround time was reduced from two days to about two hours for simple cases and two weeks to about two days for more complex cases. The resulting aerodynamic loads and convergence behavior of flow solutions computed on the automatic meshes are comparable to data computed using other methods.

In August, **Helden Aerospace** of Georgia reported on numerous grid studies as part of the **5th AIAA CFD High Lift Prediction Workshop**. The studies were completed via a unique source-based unstructured mesh adaptation capability that identifies areas for refinement via flow solutions. These flow features, or adjoint-based sources, then help engineers generate a new high-quality mesh, with targeted refinement of the critical flow areas, without the potential loss in mesh quality possible with traditional cell subdivision approaches. When coupled with the company's **HeldenMesh** grid generator, the new mesh adaptation workflow generated billion-cell meshes in under 10 minutes on a laptop. In all, 1,142 Navier-Stokes computational fluid dynamics meshes were generated during the workshop — some 1.04 trillion cells. These studies represent the type of critical grid studies needed to quantify the accuracy of advanced CFD methods and establish meshing best practices.

The **U.S. Department of Defense's High Performance Computing Modernization Program, HPCMP,** continued to expand and maintain an extensive array of supercomputers, high-speed and secure networking, and software development for science and test activities conducted by all the military services. HPCMP is approaching 20 billion core-hours of supercomputing capacity, at multiple classification levels, across the department's five supercomputing resource centers. Of particular note, in September, the **"Carpenter" supercomputer** at the **Army's Engineer Research and Development Center**, an HPE Cray EX4000, was expanded to 313,344 cores.

Between January and August, **HPCMP's Computational Research and Engineering Acquisition Tools and Environments (CREATE)** program released new versions of all products in its suite of simulation tools supporting air, land and sea vehicle acquisitions. A key thrust for the **Kestrel fixed-wing** and **Helios rotary wing** high-fidelity simulation tools was development of a performance-portable flow solver capable of executing on various types of either standard central processing units or general purpose graphics processing units. In January, the development team demonstrated one of the first-ever **overset grid simulations** in which the near-body unstructured solver, the background (off-body) Cartesian solver and the automatic domain connectivity operations were all executed on GPGPUs. Scalable performance was demonstrated on up to 100 GPGPUs. ★

Contributors: *William Chan, Earl Duque and Rick Hooker*

READ THE APPRECIATION

STEVE KARMAN, PIONEER IN UNSTRUCTURED MESHING METHODS

With more sophisticated tools, researchers study configurations and operations for future aircraft

BY IMON CHAKRABORTY

The **Modeling and Simulation Technical Committee** focuses on simulation of atmospheric and spaceflight conditions to train crews and support design and development of aerospace systems.

▲ A researcher at the University of Maryland Extended Reality Flight Simulation and Control Lab donned this full-body haptic feedback tracking suit during a flight simulation of a Sikorsky UH-60 helicopter. The haptic suit provides tactile sensations corresponding to the stick inputs the pilot should make to maintain trim attitude.

University of Maryland/Umberto Saetti

Researchers at **NASA's Ames Research Center** in California conducted the **Automation Enabled Pilot 2 simulation study** in May and June. This was the second study under **NASA's Airspace Operations and Safety Program** aimed at assessing novel automation concepts for **electric vertical takeoff and landing aircraft** that are equipped with indirect flight control systems. For AEP-2, engineers used an updated **Lift Plus Cruise aircraft model** and a simplified vehicle control concept, which included multiple assisted hover automation strategies with various levels of automation to simplify the transition from forward flight to hover. Initial results and pilot feedback confirmed the benefits of the higher automation concepts, especially in more challenging scenarios that require a higher workload.

In August, the **Simulation and Development Branch** and **Unmanned Aircraft Systems Operations Office** at NASA's Langley Research Center in Virginia led the development of **MOSAIC, the Mission Operations and Autonomous Integration Center**. From this room on Langley's campus, engineers study how small drones can be flown for applications including building inspection, environmental assessment and geographic information system mapping activities. MOSAIC's design includes access to multiple sensor streams (optical, radar and electronic) that allow operators to fly drones **beyond visual line of sight**. Achievements this year included the first BVLOS flight, development of the TAURAS airspace monitoring tool that integrates a suite of surveillance sensors into a single display, and commissioning of the Skydio Drone-in-a-Box for autonomous routine inspections.

In July, **FAA** for the first time qualified a flight simulator training device that uses **virtual reality** for its visuals. The device, developed by Swiss company **Loft Dynamics** and France-based **Airbus Helicopters**, is used by the helicopter pilot training program at **Marshall University** in West Virginia. It allows for realistic training at a much lower cost than conventional high-end simulators, and without the safety and environmental concerns of real-world flight. This first qualification of a civilian VR simulator signals a technological shift that was made possible by recent technological advances in VR, including high-resolution displays for realistic visibility of instruments and the environment; reduced latency and increased frame rates to mitigate motion sickness; and posture recognition and rendering of the pilot's limbs within the virtual environment to improve the feeling of immersion and presence. The introduction of additional technologies, including gaze tracking and artificial intelligence-based instruction, could further enhance VR training effectiveness.

In March, **Argonne National Laboratory** in Illinois released **Aeronomie**, an aircraft dynamics and power plant simulator for low-carbon aviation research. Aeronomie is intended to speed up the development of more sustainable aircraft and propulsion concepts to increase energy efficiency and reduce carbon footprint, objectives in line with the decarbonization goals set out in the **U.S. National Blueprint for Transportation**. With Aeronomie, researchers can test and validate new technologies, as well as customize a range of predefined aircraft models included in the simulator. Argonne says Aeronomie has been used to model and validate all-electric, hybrid-electric and hydrogen-powered aircraft, including a nine-passenger commuter plane and delivery drones.

In January, the **University of Maryland** established the **Extended Reality Flight Simulation and Control Lab**. In this lab, researchers create simulations of piloted and remotely operated aircraft with VR and augmented reality technology, including "full-body haptic feedback and biometry tracking suits, spatial audio, motion-base systems, and brain-machine interfaces," according to the lab's webpage. Among the lab's first research products are full-body haptic cueing control algorithms to enhance pilot-vehicle performance in degraded visual environments. ★

Contributors: *Patrick S. Kenney, Nirmit Prabhakar, Umberto Saetti, Olaf Stroosma and Peter Zaal*

Plasma and laser innovations for flight control

BY CARMEN GUERRA-GARCIA AND ANDREY STARIKOVSKIY

The **Plasmadynamics and Lasers Technical Committee** works to apply the physical properties and dynamic behavior of plasmas to aeronautics, astronautics and energy.

▲ Texas A&M University in July opened its Ballistic, Aero-Optics and Materials Facility. The first studies in this 565-meter-long, 2.4-meter-diameter chamber focused on laser propagation.

Texas A&M University

In July, researchers at **Texas A&M University** initiated the first experiments on **laser propagation** in the new 565-meter-long variable pressure **Ballistic, Aero-optics and Materials Facility.** BAM enables the study of laser propagation through turbulence, weather, aerosols and contaminated air, the validation of directed energy effectiveness for defense against practical threats, and the interaction of lasers with counter-propagating hypersonic projectiles. As of October, experiments were underway to develop and validate numerical simulation tools for prediction of turbulence influence on directed energy.

A number of tests were conducted that brought **plasma-assisted combustion** technologies one step closer to implementation in aeroengines. In February, researchers at the **Laboratoire de Physique des Plasmas at Ecole Polytechnique** and the **Institut Prime**, both in France, demonstrated that the application of **nanosecond discharges** ahead of a self-sustained detonation can reduce by a factor of two the detonation cell size, enhancing detonation for applications in **pulsed and rotating detonation engines**. In July, **MIT** researchers, in collaboration with engineers at **Specter Aerospace** of Massachusetts, demonstrated full suppression of **strong limit-cycle combustion dynamics** using nanosecond discharges. The tests were performed in a swirl-stabilized 6-kilowatt atmospheric pressure combustor over a wide range of methane/air mixtures, from fuel lean to stoichiometric. Also using a swirl-stabilized burner with nanosecond discharges, researchers at the **EM2C laboratory of CentraleSupélec** in France demonstrated a 20% extension of the operability limit (lean blowout) of pure hydrogen swirling flames and devised an actuation strategy to mitigate the nitrogen oxide emissions. Researchers from the **University of Texas at Austin** demonstrated fully coupled plasma/combustion by three-dimensional simulation of plasma-assisted ignition in turbulent reactive flows. In parallel, researchers at the **University of Minnesota** continued to develop a modeling framework that simulates in detail the discharge and combustion phases and couples them together through a detailed spatiotemporal plasma power density. The approach demonstrated good agreement with experimental measurements of gas heating, oxygen dissociation and ignition kernel evolution.

Nanosecond discharges also found applications in other areas of aerospace. In February, scientists from **Princeton University** in New Jersey demonstrated the possibility of investigating the initial phase of cavitation in a liquid, using a superstrong pulsed electric field to generate ponderomotive forces that in turn formed nanoscale discontinuities. In April, **Princeton researchers with FAA** demonstrated how a **nanosecond pulsed-periodic barrier discharge** can prevent ice formation on aircraft wings. Investigations conducted across a spectrum of flow temperatures, water droplet concentrations and sizes revealed a tenfold enhancement in energy efficiency compared to conventional de-icing techniques. Researchers from **Xi'an Jiaotong University** in China developed **super-dense array plasma actuators** manufactured from flexible printing circuit — in this case using AC voltage — capable of reducing drag by 22% for 20-meter-per-second flows.

In the hypersonics space, **Texas A&M University** researchers demonstrated how carbonaceous species could alter **hypersonic plasma** behavior. Their computational analysis focused on refractive index alterations in the vicinity of ablative surfaces on hypersonic vehicles, as well as propagation characteristics of radio signals traversing hypersonic plasma layers. Researchers from the **University of Arizona** proposed and simulated a new method for a spacecraft to enter a planet's atmosphere, which relies on magnets and avoids the use of electrodes. Using a magnetic field of around 0.1 tesla, they predicted a force of 10 kilonewtons, which can be controlled by altering the magnetic field strength. ★

Contributors: *Fabrizio Bisetti, Christophe O. Laux, Richard Miles, Bernard Parent, Svetlana M. Starikovskaia, Albina Tropina, Suo Yang and Wu Yun*

Complementary ground and flight tests advance next-generation hypersonic vehicle materials

BY AARON BRANDIS, SAVIO POOVATHINGAL AND JONATHAN BURT

The **Thermophysics Technical Committee** promotes the study and application of mechanisms involved in thermal energy transfer and storage in gases, liquids and solids.

In July, five low-cost capsules developed by **University of Kentucky** students reentered the atmosphere at hypersonic speeds, six months after being launched to the International Space Station aboard a **SpaceX Falcon 9** as part of the second **Kentucky Reentry Probe Experiment, or KREPE-2**. Prior to reentry, the capsules departed ISS aboard the **Cygnus NG-20** resupply vehicle and were ejected during the reentry burn of Cygnus. The distinct thermal protection systems materials on the capsules consisted of different variations of **phenolic impregnated carbon ablator, or PICA**, a material used for various recent NASA missions and a new variant of the 3D-printed heat shield that was previously flown on the first reentry experiment of KRUPS. All capsules contained a GPS, a nine-axis and six-axis inertial measurement unit, a high-g accelerometer, five pressure ports, thermocouples and a spectrometer to measure chemical kinetics in the hypersonic shock layer. The positions and kinematic sensors along with the science instruments provided a unique set of flight data to quantify aerothermal environments and the performance of thermal protection materials at hypersonic speeds. The flight data, which was recorded over 1,000 seconds, will be used for a wide range of analysis, including ground-to-flight traceability between ground tests and future hypersonic flights. The third mission, KREPE-3, is scheduled to fly in 2026.

In May, researchers at **NASA's Ames Research Center** in California and **NASA's Langley Research Center** in Virginia tested samples of **NuSil-coated PICA** in the Hypersonic Materials Environmental Test System high-enthalpy plasma wind tunnel. The focus was expanding the validation data envelope for the material, which served as the heat shields for NASA's Curiosity and Perseverance rovers. A PICA-NuSil heat shield will also protect **NASA's Dragonfly** quadcopter during its descent toward the surface of Saturn's moon Titan, scheduled for 2034. During the test campaign, researchers explored various combinations of carbon dioxide and nitrogen to simulate the distinct atmospheres of Mars and Titan. They also investigated parameters including heat flux, exposure duration and coating thickness. Preliminary observations revealed behavior consistent with earlier tests, although post-test analysis was ongoing as of October. In addition to helping refine the design for Dragonfly's heat shield, these results could assist researchers in validating predictive material response models and optimizing heat shield designs for future planetary missions.

In August, **GE Aerospace** completed testing of a flight-scale **dual-mode ramjet engine** in a test facility at its Evendale, Ohio, campus. The test campaign, which began in March and comprised hundreds of hours of run time, followed an 11-month-long effort to design, fabricate and install the direct connect test rig on a purpose-built thrust stand. The engine was operated over a wide range of operating conditions; these included mode transition conditions for a **turbine-based combined cycle propulsion system**, as well as Mach 4+ cruise conditions at full enthalpies and pressures expected during flight. All of the engine components were additively manufactured from conventional high-temperature metal alloys. These tests were a unique source of thrust data and other information that will assist in validating and calibrating cycle models for future hypersonic vehicle propulsion systems. ★

Contributors: *Charles Bersbach, Brody Bessire, Alessandro Turchi and Thomas West*

▶ These student-built capsules were ejected from a Cygnus supply spacecraft in July as part of KREPE-2, the second Kentucky Reentry Probe Experiment. Instruments aboard the capsules collected flight data as they plunged through the atmosphere at hypersonic speeds.

University of Kentucky

Developing parachute systems and simulating fluid-structure interactions

BY KEITH BERGERON

The **Aerodynamic Decelerator Systems Technical Committee** focuses on development and application of aerodynamic decelerator systems and lifting parachutes, pararotators and inflatables for deceleration, sustentation and landing of manned and unmanned vehicles.

▲ The U.S. Army Combat Capabilities Development Command, Soldier Center experimented with adding range to its steerable parachutes, the Long-Range Joint Precision Aerial Delivery System. In the series of tests in Eloy, Arizona, a parachute equipped with a combustion engine and propeller carried a test article to demonstrate the new capability.

U.S. Army Combat Capabilities Development Command, Soldier Center

In February, the **U.S. Army Combat Capabilities Development Command, Soldier Center**, known as DEVCOM SC, tested the Product Manager Force Sustainment System's **RRDAS, or Rapid Rigging and De-rigging Airdrop System**. To demonstrate how this parachute system can quickly get supplies to soldiers, it airdropped and automatically derigged a **Small Multipurpose Equipment Transport** vehicle at Yuma Proving Ground in Arizona. These built on the low-velocity operational testing completed at Fort Liberty in North Carolina in December 2023. This time, test engineers were able to access the airdropped vehicle up to 40% faster than current operations.

DEVCOM SC also continued to add power and range to existing aerial delivery systems. Working with other government organizations, including U.S. Transportation Command and the Office for the Under Secretary of Defense Operational Energy's Innovation Directorate, the center and industry partners conducted a series of tests in Arizona in March, July and August with a **JPADS 2K**, a variant of the Long-Range Joint Precision Aerial Delivery System. They added an **internal combustion engine and propeller** to the steerable parachute to generate enough lift to maintain flight altitude until onboard fuel was consumed, providing an order of magnitude increase in system range. In March and August, **drop tests** were performed in California with the **Precision Extended Glide Airdrop System**. For these, **paraglider wings** were released from fixed-wing aircraft to increase the range of aerial delivery systems and demonstrate how payloads could be ferried to far-away drop zones. DEVCOM SC anticipates conducting additional demonstrations of these technologies next year to mature the technology readiness.

Beyond physical tests, **DEVCOM SC modeling and simulation** efforts have helped optimize payload system dynamics for RRDAS, risk and stability assessments for towed paratrooper scenarios and helicopter/parachute sling-load operations. In June, RRDAS development simulations were completed to establish a baseline airbag model that could be repeatedly used for predictions using various vehicle or payload types and airbag vent configurations. The post-test analysis showed the impact accelerations correlated with the peak accelerations closely, with a few exceptions. Results from towed paratrooper simulations, initiated in July, led to the identification of key performance parameters for qualifying the **T-11 parachute system** for use aboard the **Airbus A400M turboprop**, supporting interoperability with allied countries.

With respect to **sling-load operations**, several new leading-edge designs for prismatic bodies were shown to reduce drag by more than 50%, while other configurations yielded a 60% decrease in pitching moment magnitude. These simulations, completed in January and February, led to a series of refined wind tunnel experiments conducted from early April to late July. The resulting drag and stability improvements have potential applications across multiple U.S. Army projects.

In July, **University of Southern California** researchers with **Butler Parachute Systems** of Virginia completed **initial high-fidelity fluid-structure interaction simulations**, as part of a study of the high-speed canopy slider used on the **HX-500/24** parachute. Initial results showed that peak forces were reduced by more than half when using the novel sombrero-shaped dynamic slider.

At **NASA's Ames Research Center** in California, researchers with the **Advanced Supercomputing Division** also completed high-fidelity fluid-structure simulations. Their work focused on the highly nonlinear inflation of a parachute in a supersonic deployment configuration, as will be required for **NASA's Mars Sample Return** spacecraft, **DaVinci** Venus probe and **Dragonfly** quadcopter. While researchers did not find parachute drag to be greatly affected by canopy porosity and viscous effects, they were able to increase drag by 20% by adding stiffness to the radial seams. ★

▲ NASA and Boeing in March released this updated rendering of the planned X-66A Sustainable Flight Demonstrator. Boeing plans to modify an MD-90 aircraft into a truss-braced-wing design.

NASA

FAA authorizes simultaneous beyond-visual-line-of-sight drone flights, and other breakthroughs

BY PRIYANK PRADEEP, SYED SHIHAB AND DAVID P. THIPPHAVONG

The **Air Transportation Systems Technical Committee** fosters improvements to air transportation systems and studies the impacts of new aerospace technologies.

In February, **passenger air travel** rebounded to pre-pandemic levels, according to the **International Air Transport Association.** IATA predicted a 10.4% increase in the **total number of global passengers** this year, as well as 5% growth in **global air cargo traffic** despite increased international trade restrictions worldwide. Global airline capacity was also expected to grow, with 1,583 **aircraft deliveries** scheduled. IATA forecasted that the airline industry will achieve profitability, with a net profit of $30.5 billion, a net profit margin of 3.1% and an operating margin of 6%.

Despite these projections, the global airline industry faced several challenges. New York-based consulting firm **Oliver Wyman** estimated a shortage of 17,000 pilots in North America, which was expected to impact airline operations and revenues. In July, a **faulty software update** by cybersecurity technology company **CrowdStrike** of Texas briefly shuttered airline reservation and flight operations systems, leading to 36,000 flight delays by the middle of the first day of the outage and approximately 10,000 flight cancellations within three days. New York-based insurance services firm **Parametrix** estimated in late July that the outage resulted in an estimated financial loss of around $860 million for six Fortune 500 airlines.

Substantial progress was made toward **UTM, Unmanned Aircraft Systems Traffic Management**. In July, in a first for U.S. aviation, **FAA** authorized multiple commercial drone operators for **beyond-visual-line-of-sight** operations in the Dallas-Fort Worth airspace. **Zipline** and **Wing** of California were approved to deliver packages while maintaining safe separation between their drones via UTM technology.

On the **advanced air mobility** front, **Joby Aviation** and **Archer Aviation**, both of California, made progress toward receiving **FAA type certification** of their **electric vertical takeoff and landing aircraft**. In February, Joby announced it had completed the third of five stages required to certify its **S4** aircraft for passenger service. In March, FAA released the **final airworthiness criteria** for Archer's **Midnight**, clarifying the path for Archer to achieve type certification.

Notable steps also occurred toward the return of civil supersonic transportation. In January, **NASA** and prime contractor **Lockheed Martin** unveiled the **X-59** demonstrator. In its **Quiet SuperSonic Technology** mission, NASA plans to fly X-59 over select U.S. communities to gather acoustics data that could help lift the ban on overland supersonic flight, ushering in a new generation of commercial supersonic aircraft. In March, **Boom Supersonic** made the inaugural flight of its **XB-1,** a one-third scale demonstrator that it calls "the world's first independently developed supersonic jet." This is a step toward proving the technology for the company's planned Mach 1.7 airliner, **Overture**.

In sustainable aviation, **NASA** and **Boeing** in March released new renderings of the **X-66A Sustainable Flight Demonstrator**, a transonic truss-braced wing (TTBW) design. NASA says this demonstrator, now in production, could slash aircraft fuel consumption and reduce emissions up to one-third compared to today's aircraft. Boeing has acknowledged that the dual status of the TTBW aircraft — folded wings and unfolded wings — would create workload and training challenges for air traffic controllers. Other areas of concern are de-icing procedures and incompatibility with certain airport runways.

In July, **AALTO HAPS Ltd.** in the U.K. announced that it had secured design organization approval from the **U.K. Civil Aviation Authority** for its solar-powered **Zephyr**, a high-altitude platform station that in 2022 set a record-breaking altitude and flight endurance in Upper Class E airspace, reaching an altitude of 75,000 feet (22,860 meters) and staying aloft for 64 days. Recent interest in such high-altitude missions has led to efforts by **FAA**, **NASA** and other organizations to research and develop **Upper Class E Traffic Management**. ★

With first flights, companies push the range of vehicle and market types

BY MICHAEL LOGAN AND MICHAEL DRAKE

The **Aircraft Design Technical Committee** promotes optimization of aircraft systems, including analysis of their future potential.

▲ Gulfstream Aerospace's first G400 completed its inaugural flight in August, powered by a blend of sustainable aviation fuel produced on the company's campus in Savannah, Georgia.

Gulfstream Aerospace

It was another fascinating year in aircraft design across multiple sectors, from advanced air mobility to uncrewed aircraft.

In March, **Boom Supersonic** of Colorado announced it had completed the inaugural flight of **XB-1**, its supersonic technology demonstrator, at the Mojave Air & Space Port in Mojave, California. The subsonic flight marked the next step toward Boom's goal of returning to supersonic travel with **Overture**, its planned Mach 1.7 passenger airliner.

In February, **Venus Aerospace** of Houston completed the first flight of its supersonic flight test drone. After being dropped at an altitude of 12,000 feet, the drone accelerated to Mach 0.9. It flew for 16 kilometers, propelled by a **hydrogen peroxide monopropellant engine**. Venus fired the engine "at 80% thrust in order to not exceed Mach 1," the company said in a press release.

In September, U.K. air taxi developer **Vertical Aerospace** said its new **VX4** prototype had completed the first phase of piloted flight tests, consisting of 20 flights from Vertical's flight test center at Cotswold Airport. Vertical aims to receive type certification of the VX4 in 2026.

In February, the **U.S. Air Force Research Laboratory** conducted the first flight of the uncrewed **XQ-67A** demonstrator, which a press release described as "the first of a second generation of autonomous collaborative platforms." With this demonstrator, AFRL aimed to prove the approach of using a common chassis — like that of a motor vehicle frame — for multiple aircraft, customizing with smaller components including software and weapons systems as needed to allow for rapid and more cost-effective replication of the aircraft.

In August, **Gulfstream Aerospace** began the flight test program for its **G400**. For its first flight, the large-cabin twinjet took off from Savannah/Hilton Head International Airport in Georgia and returned in just under three hours. Propelled by **Pratt & Whitney** engines burning a blended a sustainable aviation fuel, the aircraft reached Mach 0.85 and a maximum altitude of 41,000 feet. It's larger stablemate, the **G700**, achieved FAA certification in March and entered into service shortly thereafter.

In August, **Regent Craft** of Rhode Island received U.S. Coast Guard authorization to test the prototype of its **electric-powered seaglider**. Regent's 12-seat electric **Viceroy** is designed to cruise at 180 mph while flying 20-30 feet above the water, using the wing-in ground effect to maintain lift at a reduced drag. The craft is defined as a maritime vessel, regulated by the Coast Guard with FAA technical support.

Also in August, **Scaled Composites** announced the inaugural flight of its **Model 437 Vanguard**. Developed with Northrop Grumman, Model 437 began as a conceptual study of "multi-mission, low-cost attritable aircraft," Scaled Composites said in a release. The piloted Vanguard is a variant of the **Model 401** that Scaled Composites introduced in 2017.

In April, **Skydweller Aero** flew its **solar-powered aircraft** for the first time. The unoccupied **Skydweller**, whose wingspan is wider than that of a Boeing 747, took off and landed autonomously from Stennis International Airport in Mississippi. Skydweller was designed for "perpetual flight," which the company defines on its website as "staying aloft for 90 days or more." ★

Aircraft operations experience record traffic and renewed emphasis on safety

BY TONY EVANS AND GABRIELE ENEA

The **Aircraft Operations Technical Committee** promotes safe and efficient operations in the airspace system by encouraging best practices and information-sharing among the community and government agencies.

▲ The midflight blowout of a door plug on a Boeing 737 MAX 9 triggered an investigation by the U.S. National Transportation Safety Board and a temporary grounding of the 171 MAX 9s operated by U.S. airlines.

National Transportation Safety Board

From January to May, **U.S. air traffic delays** rose by just over 10% compared to the same period in 2023, according to the **Bureau of Transportation Statistics**. **FAA** data shows the contribution to those delays of "weather" and "equipment" decreased from 2023, while "runway" and "other/staffing" contributions increased. "Volume" contributions were about the same between the two years, despite the increase of flights and passengers this year. July 7 was one of the busiest days in history, with over 3 million passengers.

There were several incidents and deadly accidents. A runway collision at **Tokyo's Haneda Airport** in January between an **Airbus A350-900** and a **De Havilland Canada Dash 8-Q300** killed five of the six Japan Coast Guard members aboard the Dash 8. Everyone on the A350 survived. Also in January, a **door plug** blew out on an **Alaska Airlines Boeing 737 MAX 9**. All aboard survived the uncontrolled decompression, although three passengers received minor injuries. In August, a **Voepass ATR 72-500** crashed in Brazil, killing all 62 on board. In March, a LATAM Airlines **Boeing 787-9** dove unexpectedly midflight, injuring 50, and in May, one person died aboard a **Singapore Airlines Boeing 777-300ER** in a rare **fatal turbulence accident**. These accidents brought renewed attention to aircraft safety.

In February, **FAA** finalized its **Airplane Fuel Efficiency Certification rule** to reduce carbon pollution from new jets and turboprops manufactured after Jan. 1, 2028. Work continued across the community on **aviation climate impact reduction** through **optimized aircraft operations**, **contrail mitigation** and increased use of **sustainable aviation fuels**.

In June, the **European Organisation for the Safety of Air Navigation** hosted the first **Global Trajectory-Based Operations Symposium,** in which air navigation service providers and aircraft operators from around the world laid out priorities and solutions to implement the new traffic management paradigm. **FAA** and **EUROCONTROL** agreed that the **Flight and Flow Information for a Collaborative Environment** flight planning approach and connected aircraft capabilities will be instrumental to achieving the efficiency benefits of **trajectory-based operations.**

In August, **FAA's Urban Air Mobility Airspace Management Demonstration project** demonstrated how UAM corridors might work with live flights in California. In March, **NASA's Armstrong Flight Research Center** in California began preparing for studies of passenger comfort in future air taxis with tests in a new **virtual reality flight simulator**. NASA also continued developing a **UAM noise prediction tool**.

Internationally, the **International Civil Aviation Organization's Advanced Air Mobility Study Group**, established in 2023, assisted the ICAO secretariat in facilitating the safe, secure, efficient and environmentally sustainable integration of **advanced air mobility** operations and the development of the AAM ecosystem. This year, the group performed a gap analysis between existing practices, ICAO provisions and what might be required from ICAO for AAM traffic management. In Europe, the **Single European Sky ATM Research** initiative in March selected the **CORUS Five** project to extend and mature the European concept of operations for **U-Space** above very low levels and in the vicinity of controlled airports. U-space refers to the suite of procedures and technologies needed for large numbers of UAM aircraft to operate in a highly automated fashion. CORUS Five will build on achievements of the **CORUS-XUAM** project, which expand the U-space concept of operations to UAM.

In commercial space operations, 214 launches occurred as of mid-November, on track to surpass the 223 in 2023. Notable operations include SpaceX's launches of six **Starship-Super Heavy** rockets and the inaugural launches of an **Ariane 6**, Orienspace's **Gravity-1** and United Launch Alliance's **Vulcan Centaur**. SpaceX conducted 104 Falcon 9 launches as of mid-November. ★

Contributors: *Tom Reynolds and Savas Uskent*

Scientific balloons reach new heights

BY CHRISTOPHER D. YODER AND PAUL VOSS

The **Balloon Systems Technical Committee** supports development and application of free-floating systems and technologies for buoyant flight in the stratosphere and atmospheres of other planets.

▲ The Japan Aerospace Exploration Agency, JAXA, in July concluded a series of balloon flights, including the Biopause mission. Shown here being prepared for flight, the Biopause balloon lofted a sampling platform (far right) to collect stratospheric microbes. Researchers aimed to determine the boundary at which atmospheric conditions become too harsh to support life.

JAXA

Aerostar of South Dakota achieved several firsts, beginning in January with the inaugural launch, operation and recovery of a **Thunderhead** balloon, which uses hydrogen as a lift gas. In mid-October, Aerostar reached 673 consecutive days of having at least one balloon aloft in the stratosphere, in some cases for 150 consecutive days. In business news, Aerostar in March acquired Near Space Corp. of Oregon.

In February, **NASA's Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory** concluded its flight, setting a NASA record for heavy-lift, long-endurance balloons. In January, the **AESOP-Lit** set an altitude record, reaching over 157,511 feet (48 kilometers) over Antarctica. And in September, NASA determined that a 60 million-cubic-foot balloon set an altitude record for a NASA balloon flown from Sweden. Another five launches were planned to occur by the end of 2024.

In July, **JAXA, the Japan Aerospace Exploration Agency**, completed a four-balloon campaign from **Taiki Aerospace Research Field**. The campaign included missions for technology development for a deep-space sample return capsule, Martian propeller concepts, stratospheric microbe collection and optical links between balloons and a ground station. In July, Japanese startup **Iwaya Giken** completed a test flight of its crewed balloon system for space tourism. The balloon exceeded 20 kilomters in altitude, an unofficial record for crewed flight altitude from Japan. In March, researchers at **Smith College** in Massachusetts and the **Alfred Wegener Institute for Polar and Marine Research** in Germany collaborated on five flights of controlled meteorological balloons, studying **Arctic warm-air intrusions** near Svalbard, Norway. In May, **World View** of Arizona announced **World View Indo-Pacific**. This wholly owned subsidiary, based in Australia, is to open a manufacturing facility and oversee stratospheric remote-sensing and space tourism operations in the region.

Urban Sky of Colorado achieved several milestones, including completing some 100 of its Microballoons, ranging in volume from 45 to 180 cubic meters. In January, Urban Sky won first place in the **U.S. Army's National Security Innovation Network's Small Tactical Aerial Platforms for Extended Loitering Challenge**. In August, the company was awarded $2.6 million from **NASA's FireSense project** to develop a wildfire detection sensor.

Sandia National Laboratories of New Mexico and **Pacific Northwest National Laboratory** of Washington collaborated under the **U.S. Department of Energy's Triton initiative** to fly tethered balloons for marine wildlife monitoring in coastal California. In January, a field study evaluated the effectiveness of a tethered balloon equipped with thermal imagers for tracking and detecting wildlife near prospective offshore wind and marine energy installations.

In April, **Sandia** launched four balloons to observe the solar eclipse. In June, the lab partnered with **Oklahoma State University** to launch a record-setting 11 **heliotropes** — solar-heated hot-air balloons — from **Belen Regional Airport** in New Mexico, setting an internal record for the most launches in a day. Additionally, a 10-meter diameter balloon reached a stable altitude of 65,000 feet (19.8 km) carrying a 5-kilogram payload, the heaviest launched by Sandia's heliotrope program.

The **Physical Science Laboratory at New Mexico State University** completed outreach events for the **Nationwide Eclipse Ballooning Project**. In April, 25-plus sounding balloons were launched from Granbury, Texas. In July, some 35 teachers participated in a **Teachers in Space** and **New Mexico Space Grant Consortium** balloon workshop.

In August, **StarSpec Technologies** of Canada completed a test flight at the Fort Sumner balloon facility in New Mexico for **NASA's Exoplanet Climate Infrared Telescope** mission. EXCITE, built on the high-stabilized balloon-borne platform developed for the **SuperBIT** mission, has the 50-milliarcseconds stability required to measure precise spectra of exoplanets and their host stars in a near-space environment. ★

Contributors: *Mary L. Bowden, Andrew Denney, Darielle Dexheimer, Hide Fuke, Jared Leidich, Anastasia Quanbeck, Erika L. Roesler, Javier Romualdez and Phil Wocken*

Pushing the envelope on electric aircraft technologies

BY PHILLIP ANSELL

The **Electrified Aircraft Technology Technical Committee** supports the integration of electrified aircraft systems through the design, evaluation and application of key technologies, including components for propulsion, actuation, safety, airworthiness and thermal management.

▲This subscale demonstrator, developed during Europe's Clean Sky 2 program, made its first flight in July. The remotely piloted flights were to assess how distributed electric propulsion designs might be scaled up for commercial passenger airliners.

Delft University of Technology

The year's milestones in electrified aviation technologies included advances in **high-power electrical systems**, first flights of various novel aircraft concepts and committed support from industry and government stakeholders to continue developing electric flight technologies.

In January, the **Airbus ZEROe** team announced the first powered tests of its 1.2-megawatt powertrain, comprised of hydrogen fuel cells and an electric power system representative of one that could be installed on a fully electric airliner, one of four hydrogen concepts the company is evaluating for its next passenger plane. Also in January, **Electra** of Virginia surpassed 2,000 preorders for its **hybrid-electric short takeoff and landing aircraft**, which the company unveiled in November. In April, **U.S. Navy** and **U.S. Army** announced new awards in Electra to further refine the company's concept.

In March, **FAA** issued a **light-sport aircraft airworthiness exemption** for the **Pipistrel Velis Electro**, permitting the battery-electric aircraft to begin flight training activities within the U.S. Later that month, Pipistrel announced it had constructed its 100th Velis Electro. In May, **New Vision Aviation**, a flight school in the San Joaquin Valley of California, began flight training with the Velis Electro, the first such program in the U.S.

In April, **NASA** and **magniX** of Washington completed the first phase of testing in **NASA's Electric Aircraft Testbed** facility in Ohio through the **Electrified Powertrain Flight Demonstration** project. Tests of magniX's electric engine were conducted to qualify powertrain components under simulated high-altitude flight conditions, varying ambient temperatures, and high power levels. magniX is retrofitting a **De Havilland Dash 7** with the powertrain for flight demonstrations, planned for 2026.

Also in April, **ZeroAvia** announced the opening of a new facility in Everett, Washington, for the production of the firm's **hydrogen-electric propulsion systems** and research and development operations.

May marked the first flight of a **distributed electric propulsion demonstrator** developed under the **European Union Clean Sky 2** research program. The remotely piloted subscale aircraft has a wingspan of 4 meters, a takeoff mass of 167 kilograms and a cruise speed of 100 knots. The objective of the flight test campaign is to explore the potential of distributed electric propulsion for large commercial aircraft to enhance performance and control.

In July, **Joby Aviation** of California conducted the first flight of its **hydrogen-electric technology demonstrator**. The vertical takeoff and landing aircraft flew 523 miles (842 kilometers), propelled by a liquid hydrogen and fuel-cell system developed by Joby subsidiary, **H2FLY.** This flight test marked a dramatic increase in range capability for electric propulsion, relative to previous flights Joby has conducted with its battery-electric prototypes.

This year also saw the introduction of several new **fully electric aircraft concepts** configured to serve commercial markets. In January at **AIAA's SciTech Forum**, Dutch startup **Elysian Aircraft** unveiled its concept for a regional aircraft intended for 90-passenger flights up to 500 miles (805 km). This **E9X** concept features distributed propulsion, with eight electrically driven propellers mounted across the wing, which at 138 feet (42 meters) would be substantially larger than incumbent aircraft for this market. In March, **Whisper Aero** of Tennessee revealed its **Whisper Jetliner**, a 100-passenger aircraft intended to serve markets up to 769 miles (1,238 km). The aircraft features **electric ducted fans** distributed across the wings' leading edges to enhance the high-speed lift to drag performance. ★

Contributors: *Reynard de Vries, Maurice Hoogreef and Virginia Stouffer*

Low and slow to high and fast marks flight tests

BY JESSICA PETERSON, ANDY FREEBORN AND KARL GARMAN

The **Flight Testing Technical Committee** focuses on testing of aircraft, spacecraft, missiles or other vehicles in their natural environments.

Electric vertical takeoff and landing technology saw significant advancement globally, with numerous flight tests. In April, **BETA Technologies** of Vermont achieved its first piloted transition flight with its ALIA 250 in New York, demonstrating a shift from vertical and horizontal wing-borne flight. In May, **Joby Aviation** of California announced the completion of 1,500 flights with its two preproduction prototypes. In June, Joby conducted a 523-mile (842-kilometer) flight with a new **hydrogen-electric demonstrator**, demonstrating emission-free flight. Also in June, **Archer Aviation's Midnight** eVTOL demonstrated the transition from vertical to wing-borne flight. Days later, China-based **EHang** performed its first autonomous eVTOL flight in Saudi Arabia. And in August, Germany-based **Volocopter** began crewed eVTOL tests at a vertiport testbed in France.

In the field of **supersonic flight, NASA** and prime contractor **Lockheed Martin** formally debuted the **X-59** demonstrator, with which they plan to gather community response data about quieter supersonic flight. In March, **Hermeus** of Atlanta unveiled its remotely piloted **Quarterhorse Mk 1** test aircraft, a step toward producing the world's first reusable hypersonic plane. Late in March, **Stratolaunch's TA-1** reached supersonic speeds during the design's first powered flight. Also that month, **Boom Supersonic's XB-1** demonstrator made its inaugural flight, the first of 10 planned subsonic flights before the demonstrator goes supersonic.

▼ One of Joby Aviation's electric air taxi prototypes flies over the company's facility in Marina, California. Joby said in May that it surpassed some 1,500 flight tests toward its goal of receiving FAA type certification in 2025.

Joby Aviation

Beyond these developments, the aviation sector saw other first flight events. In August, **Gulfstream Aerospace Corp.** completed the first flight of a **G400** luxury jet in Georgia, marking the start of its test program. The same month, California-based **Scaled Composites' Model 437 Vanguard**, a crewed prototype of a low-cost attritable aircraft with a Pratt & Whitney 535 engine, made its inaugural flight.

Aerospace innovation continued at the **U.S. Air Force Test Pilot School**. In May, **Air Force Secretary Frank Kendall** flew in the artificial intelligence-controlled **X-62A VISTA** over **Edwards Air Force Base** in California, with a safety pilot in the back seat. In this flight, X-62A, equipped with **machine learning-based autonomy** as part of a **DARPA** program, demonstrated the ability to perform complex tactical maneuvers autonomously while live agents responded in real time to simulated threats. Also in May, students from the **Space Test Course** at the Test Pilot School for the first time operated a satellite in orbit from Edwards. Achieved through a partnership with the **Air Force Research Laboratory's Space Vehicles Directorate**, this milestone was a step toward advancing space test operations and multidomain education.

Finally, commercial space conducted some notable flights. In May, **Blue Origin's New Shepard** resumed crewed suborbital flights after a nearly two-year hiatus. Among the six-person crew was **Ed Dwight**, a former Air Force test pilot who in the 1960s was the first Black astronaut candidate. This was Dwight's first spaceflight. In June, **SpaceX** achieved the first intact reentry and splashdown of a **Super Heavy** booster and **Starship** upper stage during the design's fourth flight from Boca Chica, Texas. Also in June, a **Boeing CST-100 Starliner** launched from Florida with two astronauts for the design's first crewed flight to the **International Space Station**. Starliner experienced helium leaks and thruster degradation while en route, so NASA decided to return the capsule unoccupied in September, and plans to return the astronauts in February on a **SpaceX Crew Dragon**. Days after Starliner's launch, **Virgin Galactic** made the final flight with its **VSS Unity**, the first commercial spaceplane to reach space. The company is now focused on developing its new Delta-class vehicles.

These achievements across aviation and space underscore a transformative period in flight testing, promising even greater advancements and innovations in the years to come. ★

Contributors: *William Childress and James Sergeant*

Focus increases on electric and autonomous aircraft technologies

BY ERIC MILLER

The **General Aviation Technical Committee** fosters research and development related to general aviation technologies and systems and serves as an advocate for general aviation awareness.

The general aviation community made significant **flight testing** strides in 2024 toward a sustainable future. In May, FAA released its "Air Traffic by the Numbers" report of 2022 general aviation flights. There were 26.9 million general aviation flight hours, a slight increase from the 26.4 million hours recorded in the 2021 survey. There were 209,540 active general aviation aircraft across the U.S. The report also contained select results from 2023, including that the number of active pilot certificates increased 6.6% to 806,939, and remote/drone pilot certificates increased 21.2% to 368,633. As of September, there were 5,165 public use airports and 14,458 private use airports across the country.

In February, **Reliable Robotics** and **FAA** made progress in the area of autonomy certification, agreeing to the testing and analysis that the California-based company plans to conduct to demonstrate that its **continuous autopilot engagement system** satisfies FAA safety and performance requirements. The company plans to retrofit a **Cessna Caravan 208** for autonomous taxi, takeoff and landing operations.

In March, **Gulfstream Aerospace Corp**. announced that its **G700** had received FAA type certification. The G700 is the fastest business jet design in the Gulfstream fleet, with a maximum operating speed of Mach 0.935.

In April, **BETA Technologies** of Vermont completed a piloted transition flight with its **ALIA 250** electric vertical takeoff and landing prototype, starting from vertical lift and transitioning to forward cruise on fixed wings. BETA is also developing a conventional takeoff and landing variant of ALIA and plans to commercialize both aircraft in the coming years.

In May, Virginia-based **Electra** demonstrated ultra-short takeoffs and landings with its **EL-2 Goldfinch** demonstrator. The aircraft operated with less than 300 feet (91 kilometers) of runway, opening access to locations only helicopters can reach. The Goldfinch ultizes a **blown-lift design** with eight electric motors to significantly increase lift, allowing the hybrid-electric aircraft to take off and land in just one-tenth of the space needed by conventional aircraft. Electra in November unveiled the design for a nine-passenger aircraft, the **EL9 Ultra Short,** with entry into commercial service planned under **FAA Part 23** regulations.

In June, **Archer Aviation** of California received its **Part 135 Air Carrier and Operator Certificate** from **FAA**, the second air taxi developer to do so. This certificate allows Archer to begin flying conventional aircraft to refine its air taxi operations and procedures. Archer in September announced it had reached a milestone of 400 test flights this year.

In May, **Joby Aviation** of California announced completion of its preproduction flight test program and that it was moving onto the next phase of flight testing with its **S4** air taxis. That preproduction phase included carrying out 31 piloted flights in two days in January. Those flights, conducted with FAA, demonstrated the S4's **operational characteristics and precision landing capabilities**. Joby in May said it had completed 1,500 with its two preproduction aircraft over the past four years, including some 100 flights with a pilot onboard. In July, Joby announced it had flown a new **hydrogen-electric demonstrator** for 523 miles (942 kilometers), with water as the only byproduct. The flight demonstrated the potential benefits of hydrogen technology. ★

▶ Virginia electric aircraft developer Electra this year began ultra-short takeoffs and landings with its EL-2 Goldfinch demonstrator, pictured here at the company's hangar at Manassass Regional Airport. The company is designing a nine-passenger production plane that could take off and land in as little as 45 meters.

Aerospace America/Paul Brinkmann

Hypersonic flight tests get democratized

BY LIZ STEIN AND DAVIDE VIGANÒ

The **Hypersonic Technologies and Aerospace Planes Technical Committee** works to expand the hypersonic knowledge base and promote continued hypersonic technology progress through ground and flight testing.

▲ Among the craft that completed hypersonic flight tests this year were (clockwise from top left) multiple SpaceX Starship upper stages, a Varda Space Industries capsule, Stratolaunch's Talon A-1 testbed and the BOLT IB test article flown by the Johns Hopkins University Applied Physics Lab and the German Aerospace Center.

Varda Space Industries, SpaceX, Stratolaunch, JHU APL

Academia saw funding directed toward development of **high-temperature hypersonic materials research**. In March, the **U.S. Department of Defense** awarded $7.5 million to a team led by the **Missouri University of Science and Technology**. In May, **NASA** awarded **Wichita State University's National Institute for Aviation Research** $10 million.

Significant funding was also allocated to continue development of ground testing facilities. Announced in January, the **University of Central Florida** will build a midscale, high-enthalpy propulsion testing facility; the **University of Illinois** will develop a high-enthalpy wind tunnel focused on propulsion physics research; and the **University of Tennessee** plans to upgrade its 500-kilowatt pulsed arc-jet facility for continuous operations. In addition to these developments, the Pentagon in March announced plans to construct a new hypersonic ground testing track, further bolstering U.S. testing and evaluation infrastructure.

Also this year, the promise of commercial hypersonic flight testing became reality. **Varda Space Industries** in February and **SpaceX** in March, June, October and November gathered videos of reentry plasma during flight tests. Varda recorded and played back the video of its **W-1** capsule's flight, while SpaceX hosted live broadcasts. The June flight marked the first time a **Starship** upper stage survived reentry, and in November a Starship reignited an engine in space before splashing down in the Indian Ocean. In March, **Stratolaunch** achieved its first hypersonic flight, reaching Mach 5 with its **Talon-A1**.

In September, **Hermeus** of Georgia broke ground on its engine and flight test facility in Jacksonville, Florida, further proving that private capital is willing to take on technology development risks that were once the sole domain of nation states.

Government-sponsored hypersonic flight testing continued its trend from prior years but with a better success rate, signaling significant progress. In March, the **U.S. Air Force** tested its **Air-launched Rapid Response Weapon** for perhaps the final time before this air-to-ground missile is moved into production. In June, the **U.S. Army** deployed its ground-launched **Long Range Hypersonic Weapon** in a joint exercise with the **U.S. Navy**. Also that month, the **Missile Defense Agency** conducted the first flight of its **Hypersonic Testbed**, a Kratos-built craft designed to gather flight data and accelerate hypersonic development. In September, the **Johns Hopkins University Applied Research Laboratory** and the **German Aerospace Center, DLR**, conducted a joint test in Norway of their **BOLT-1B** vehicle. They gathered information on boundary-layer transition and turbulent flow.

International developments continued their upward trajectory for investment and collaboration. In May, the U.K. awarded a $1.3 billion contract to Australia's **Hypersonix Launch Systems** and Canada's **Space Engine Systems** for the development of new hypersonic weapons. Also in May, the U.S. and Japan expanded their cooperation in hypersonic defense by signing an agreement to co-develop a **hypersonic interceptor vehicle**. Japan in July released footage showing its progress in developing its **Hyper-Velocity Gliding Projectile**. In March, Kyiv researchers reported the first battlefield use of **Russia's Zircon hypersonic missile**. North Korea claimed a successful ground test of its first solid rocket motor propulsion system for its intermediate range hypersonic missile in March. North Korea appeared to conduct the first flight test in July, but South Korean officials reported that the missile exploded in midair.

Defense contractors saw significant investment in hypersonic technologies. **Lockheed Martin** secured two major contracts: $756 million in May for the **LRHW missile** and a $534 million award in June for the **Conventional Prompt Strike hypersonic boost-glide missile**. **Raytheon** in January received a $407 million contract from the **Air Force** to continue development of the **Hypersonic Attack Cruise Missile**. In July, the **U.S. Army** confirmed plans to begin deploying hypersonic weapons in Europe by 2026. ★

Largest airship since Hindenburg begins test flights, other ventures progress toward commercialization

BY ALAN FARNHAM

The **Lighter-Than-Air Systems Technical Committee** stimulates development of knowledge related to airships and aerostats for use in a host of applications from transportation to surveillance.

READ THE APPRECIATION

LOUIS FOLTZER, A DRIVING FORCE BEHIND GOVERNMENT AND INDUSTRY AIRSHIP PROGRAMS

In October, California-based **LTA Research** began outdoor, untethered test flights with its **Pathfinder 1** prototype. The largest aircraft in the world as well as the first rigid airship to be built in 85 years, Pathfinder 1 is comprised of advanced materials including carbon fiber and has **diesel-electric propulsion**, though plans call for later transitioning to **hybrid-electric**. Plans call for 25 low-level test flights over and around San Francisco Bay, for a combined 50 hours.

In August, **Sceye** of New Mexico announced it completed a **diurnal stratospheric flight**, in which its remotely piloted airship kept position over a fixed area for 24 hours, using solar power during the day and battery storage at night. The company called this a precursor to longer-duration flights with such **high-altitude platform systems,** or **HAPS.**

In June, **Hybrid Air Vehicles** of the U.K. announced the accrual of £1.4 billion ($1.8 billion) in reservations for its **Airlander 10** hybrid airships. This includes 20 craft reserved last year by Spanish regional airline **Air Nostrum**, an unspecified number by French ecotourism company **Grands Espaces,** and six by the **Highlands and Islands Transport Partnership** for transporting cargo and passengers throughout the Scottish Isles. HAV said in February that it had begun the type certification process for Airlander 10 and that the company selected Doncaster, South Yorkshire, for the site where it will employ about 1,200 people and fabricate 24 craft per year.

In May, **Goodyear** unveiled a new base for its European airship operations at **Mülheim/Essen Airport** in Germany. In April, China's state-owned conglomerate **Aviation Industry Corp.** said its multipurpose civilian airship, **AS700**, made its first ferry flight and that 18 were on order, with deliveries scheduled before the end of the year.

In January, California-based **H2 Clipper** announced it received a patent for building large rigid airships by means of "swarm robotics" — a technique that the company said could radically reduce the cost and time required for constructing its planned hydrogen-powered airships.

In February, **Flying Whales** of France announced it will locate manufacturing facilities for its proposed 60-ton lift **LCA60T** hybrid cargo airship in Australia and the United Arab Emirates.

In August, **Galaxy Unmanned Systems** of Texas announced it had begun planning to send one of its uncrewed craft on an autonomous nonstop flight around the world in 2029. The mission is intended to demonstrate the company's artificial intelligence technology and pay homage to the Graf Zeppelin's 1929 circumnavigation, the first such flight by an airship. The announcement followed one by British airship operator **Straightline Aviation** of its own proposed nonstop circumnavigation with a piloted **Z1** hybrid airship, made by **AT Squared Aerospace** of California.

In supply chain news, Russian scientists, writing in the August issue of the journal Fuel, announced the discovery of a process for producing hydrogen in situ by injecting steam and a catalyst into natural gas wells and then igniting the gas. The authors said this process yields a mixture of gases from which hydrogen can be extracted with 45% efficiency. In February, Canada-based **Pulsar Helium** announced the discovery of a **helium deposit** in Minnesota it called the "richest in the world" and one of the most concentrated. Market expert Phil Kornbluth predicted that helium supply and demand will remain substantially in balance for the foreseeable future. ★

▼ LTA Research of California completed the first outdoor, untethered flight of its Pathfinder 1 rigid airship in October.

LTA Research

▲ Aurora's conceptual vertical takeoff and landing demonstrator, shown in an illustration, was one of two concepts chosen by DARPA in May for continued design work under its SPRINT program. Competitor Bell Textron is working on a folding rotor design.

Aurora Flight Sciences

Leveraging past vertical-lift technology for today's aircraft

BY ERASMO PIÑERO JR.

The **V/STOL Aircraft Systems Technical Committee** is working to advance research on vertical or short takeoff and landing aircraft.

Many of today's programs and initiatives to develop **vertical takeoff and landing aircraft** are looking at technologies that were tested during the 1960s, the heyday of VTOL research in the United States and Europe. Among them is the **Speed and Runway Independent Technologies, or SPRINT**, a joint DARPA/U.S. Special Operations Command program to build a VTOL X-plane. In May, **Aurora Flight Sciences** of Virginia and **Bell Textron Inc**. of Texas were downselected for Phase 1B of SPRINT to complete preliminary design of their concepts. With the SPRINT plane, DARPA wants to demonstrate technologies for runway independence applicable to the next generation of air mobility platforms.

Bell validated its preliminary design for SPRINT with a **risk-reduction test** conducted at **Holloman Air Force Base** in New Mexico in late 2023. In a sled test on the **Holloman High Speed Test Track,** Bell demonstrated a folding rotor as part of a multimode propulsion system. Folding rotor technology was researched in the 1960s and early 1970s. For its SPRINT concept, Bell is leveraging its previously developed **high-speed VTOL, or HSVTOL,** technology, "which blends the hover capability of a helicopter with the speed (400+ knots), range and survivability of jet aircraft," according to a press release.

Aurora in May unveiled its SPRINT concept: a three-fan-in-wing HSVTOL. The wing fans are covered by semicircular upper doors that would open and close for different flight regimes, as was done in the **Ryan XV-5 Vertifan** experimental VTOL that first flew in 1964. The concept revolves around a blended-wing-body fuselage with a forward fan covered by a door that slides aft and symmetrical louvers embedded in the wing that vector fan thrust for control in vertical flight. The XV-5 also had lateral louvers under its wing fans for control, and its lift fans were tip-driven by diverted engine exhaust gases. Aurora has not revealed how the lift fans on the wings will be powered. Like Bell, Aurora's goal is to design a VTOL that can reach a cruising speed of 450 knots, with the objective of scaling up the demonstrator to a larger transport aircraft.

In the commercial electric VTOL world, California air taxi developer **Joby Aviation** in May concluded a preproduction flight test program that began four years ago. The company has since transitioned to initial aircraft production and test flights with a production-conforming prototype for type certification purposes. The preproduction flight test phase comprised 1,500 flights, including about 100 flights with a pilot onboard, and a total distance of 28,700 nautical miles (53,152 kilometers).

V/STOL research in academia also made significant contributions to powered lift. Over the past two years, the **Eagle Flight Research Center at Embry-Riddle Aeronautical University** in Florida has flown a 36-kilogram uncrewed **distributed electric propulsion quad-helicopter**, supported by FAA funding. As of August, the helicopter had completed a series of tests, demonstrating stable hover and maneuvering flight after a rotor failure. This is one key safety aspect that will receive lots of attention from federal agencies and the V/STOL community in the coming years, as eVTOLs proliferate. ★

Aviation and space sectors tackle growing threats with task forces and regulatory action

BY KRISHNA SAMPIGETHAYA, GABE ELKIN AND BRANDON BAILEY

The **Aerospace Cybersecurity Working Group** provides awareness, education and standards development to help protect aerospace's digital infrastructure.

▲ Among the aviation cyberattacks this year was one on Seattle-Tacoma International Airport in late August. The Port of Seattle, which operates the airport, in September attributed the attack to the ransomware group Rhysida.

Skidmore, Owings & Merrill/Dave Burk

For the aviation sector, the safety threats from **global navigation satellite system spoofing and jamming** continued to grow. To address this, the **European Union Aviation Safety Agency** and **International Air Transport Association** met in January to improve data sharing, develop resilient technologies and raise awareness among pilots and air traffic controllers. With some 1,350 flights daily disrupted by spoofing and other critical aircraft systems affected, a 450-member global task force was formed and published a report in September.

Ransomware and distributed denial-of-service attacks continued to disrupt air travel. In August, a cyberattack on **Seattle-Tacoma International Airport** disrupted internet, phone, email and other essential services. In June, the **International Civil Aviation Organization** outlined priorities for member states to address cyberattacks in its **Global Aviation Security Plan**. The **U.S. Department of Homeland Security's Cybersecurity and Infrastructure Security Agency, CISA,** proposed new regulations under the **Cyber Incident Reporting for Critical Infrastructure Act**, creating requirements for reporting aviation cyber incidents and ransom payments.

Although not a cyberattack, the faulty software update from **CrowdStrike** that caused a global IT outage in July demonstrated the implications of cyber issues. Major airlines worldwide were grounded for days, and thousands of flights were canceled. In February, the **FlyCASS** web service faced a ransomware attack. An elemental security flaw with this service, which manages the Known Crew Member program and Cockpit Access Security System, was reported to the Department of Homeland Security in April.

Amid increasing attention on space cybersecurity, **NASA** in January released its first **Space Security Best Practices Guide**, and the White House announced plans for minimum cybersecurity standards for space systems. In May, a NASA Government Accountability Office report urged the agency to update its spacecraft acquisition policies to include cybersecurity protections.

The **Japan Aerospace Exploration Agency** reported ongoing cyberattacks, though none involved sensitive data. The **Space Information Sharing and Analysis Center** highlighted over 100 weekly attacks on the commercial space sector, pointing to a lack of coordination and resources. In April, the **Aerospace Corp.** published a **Space Segment Cybersecurity Profile** for threat-focused risk assessments, based on the NIST 800-53B standard.

Drone security remained a concern. In January, the **FBI and CISA** raised alarms about purchasing Chinese-manufactured drones, due to the potential for the Chinese government to access their information. As of March, **FAA's Remote ID mandate** requires drones over 0.55 pounds to broadcast identification and location data, though concerns about Remote ID security and privacy persist.

In May, President Joe Biden signed the **FAA Reauthorization Act of 2024**, which grants FAA authority to create regulations for civil aircraft cybersecurity, establishes a cyber threat management process for the national airspace system, mandates regular avionics screenings and sets up a committee for cybersecurity standards. FAA is also tasked with investigating **network-based Remote ID** for drones. The act also requires appointing a cybersecurity lead and a GAO review of aircraft cybersecurity. In August, FAA proposed new cybersecurity rules for airworthiness certification of transport category civil aircraft.

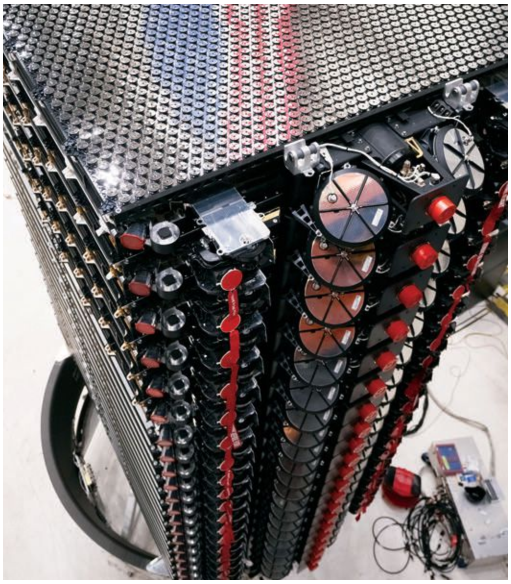
Events hosted by the **DHS-Department of Defense-FAA Aviation Cyber Initiative's Cyber Rodeo** continued to enhance the aviation community's collaboration and resilience. In April, **Embry-Riddle Aeronautical University**, in partnership with **NASA** and the **National Science Foundation**, hosted a workshop at its Prescott campus on advancing technology, research and education in aviation cybersecurity. **The Aerospace Village and Aviation ISAC** also hosted events and discussions, including at **DEF CON 32** in August. Also, a Cal Poly report, funded by the National Science Foundation and published in June, emphasized space as a critical cybersecurity frontier. ★

Contributor: *Arun Viswanathan*

Communications satellites continue proliferation into new orbits with expanding services

BY RABINDRA (ROB) SINGH

The **Communications Systems Technical Committee** is working to advance communications systems research and applications.



SpaceX in January launched the first six Starlink satellites capable of providing direct-to-cell internet. Since then, some 200 satellites have been launched for internal tests.

SpaceX

This year, we noted expansion in the new space domain with the emerging very low-Earth orbit domain and the cislunar and lunar domain, in addition to the always active LEO, MEO and GEO market domains.

VLEO — very low-Earth orbit (400 kilometers or below): In June, **DARPA** awarded a contract to **Redwire** of Florida to be the "prime mission integrator" for the agency's **Otter "air breathing" electric propulsion demonstration**. A **Redwire SabreSat VLEO spacecraft** will be developed into an "orbiting wind tunnel" to test one or more techniques for gathering and ionizing air at VLEO altitudes. This could potentially create "a virtually unlimited supply of propellant" for satellite electric propulsion at these altitudes, DARPA explains. In April, DARPA awarded a $14.9 million Otter contract to **Phase Four**, an electric propulsion company in California, for its thruster technology.

LEO — low-Earth orbit (400-2000 km): The most prolific orbital altitude surpassed 8,110 satellites in September, of which 6,350 were from SpaceX's megaconstellation **Starlink**, two were from Amazon's competing constellation, **Kuiper**, and 634 were from **OneWeb**. This emerging market has been driving new direct-to-device satellite demonstrations and services, including **Apple's Emergency SOS via Satellite service**, provided by Globalstar satellites. In May, **AT&T** announced an agreement with **AST SpaceMobile** of Texas, which is creating a space-based broadband cellular network, to provide services to its customers. In September, **AST** announced that the first five of its **BlueBird satellites** reached orbit safely. **SpaceX** in January launched the first of its **direct-to-device Starlink satellites** and as of early August had commissioned about 100 of them.

MEO — medium-Earth orbit (2,000-36,000 km): As of June, there were 199 satellites in MEO, the prime location for all global navigation satellite system constellations. In September, the **U.S. Space Force** announced agreements with four companies to produce design concepts for small satellites to augment today's GPS constellation under the **Resilient GPS initiative**. Concepts for these **Lite Evolving Augmented Proliferation, or LEAP, satellites** will be created by **Astranis, Axient, L3Harris and Sierra Space**. In the missile defense domain, Boeing subsidiary **Millennium Space Systems** this year became the sole remaining spacecraft contractor for Space Force's **Epoch 1** program to send missile tracking warning satellites to MEO. Also, this regime is finding growing application for commercial communications and defense monitoring. In April, **SES**, the Luxembourg-based satellite operator, announced that its **O3b mPOWER constellation** was operational.

GEO — geosynchronous orbit (36,000 km): As of June, there were some 552 satellites in GEO. We continue to see a shift from large-scale GEO satellites to smaller and MicroGEO satellites. In March, for example, **Astranas**, San Francisco maker of MicroGEO satellites, announced that it will provide a satellite to **Thaicom**, an Asian satellite operator, and one for **Orbith**, a Latin American internet provider, for service in Argentina. Also in March, **Boeing** received a contract from the Space Force to build **WGS-12, the next Wideband Global Satcom satellite**. In June, **Airbus Defence and Space** announced that it has been contracted by **Yahsat** of the United Arab Emirates to build the **Al Yah 4 and Al Yah 5 satellites**.

Cislunar/lunar: The volume of space beyond GEO is of increasing interest to commercial companies as the U.S., and other governments are making plans to explore the moon and open it up to economic activity. In September, **Intuitive Machines** of Texas received a NASA contract that could be worth up to $4.82 billion to provide **lunar relay satellites** and other equipment services to the agency. ★

Computing enables Voyager's revival, next-gen space computers and AI

BY RICK KWAN AND ARCHANA TIKAYAT RAY

The **Computer Systems Technical Committee** works on advancing the application of computing to aerospace programs.

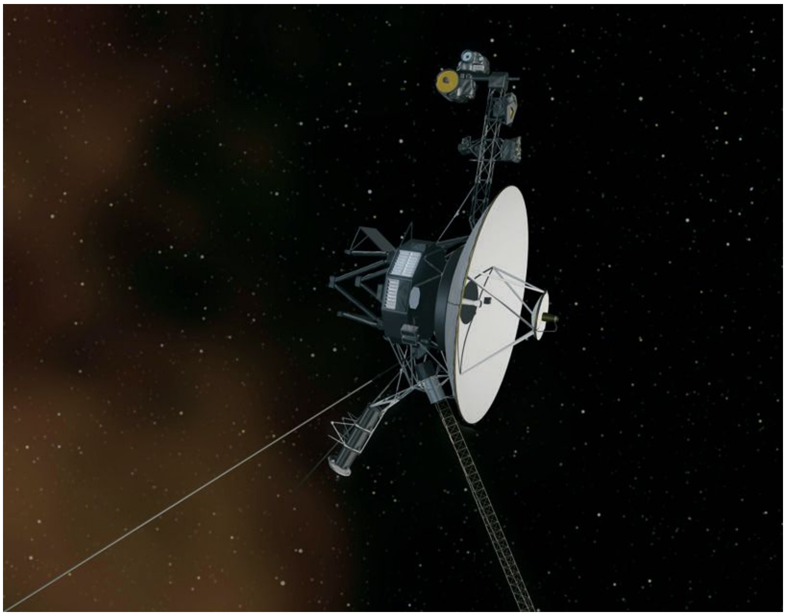
In April, NASA's **Voyager 1** resumed returning science data from its instruments. Voyagers 1 and 2 are the only spacecraft to directly sample **interstellar space**. In November 2023, Voyager 1 data was suddenly stuck in a repeating pattern. After studying decades-old engineering documents, the Voyager team sent a "poke" command to the spacecraft in early March; it revealed that a single **memory chip** in the **Flight Data Subsystem,** one of the three onboard computers, had failed after 46 years of spaceflight. The team moved code to other parts of FDS memory and in mid-April, uplinked code for returning the spacecraft's engineering data. With Voyager 1 at a distance of 22.5 light hours from Earth, it was two days before they learned that the modification had worked. They then began rebuilding the code that returns science data. In May, two of the four science instruments began returning good data, and all four instruments were returning data as of June. When it was launched, the Voyager FDS had a **software testbed and assembler**. Decades later, with no expectation that Voyager would last so long, they were decommissioned. Now, however, a new simulator and assembler development effort is underway.

NASA's High-Performance Spaceflight Computing program got its first silicon parts for the **PIC64-HPSC** family of microprocessors by **Microchip**, based in Arizona. This first Microchip component is a pin-compatible engineering model for software development activities. Announced in July, the PIC64 chip has eight processor cores built on the **SiFive X280**, a 64-bit central processing unit that uses the **RISC-V** open standard architecture. The chips are fabricated with the 12-nanometer **12LP+ process** at New York-based **GlobalFoundries**, a Department of Defense-accredited Trusted Foundry. The PIC64 effectively replaces the **RAD750** from **BAE Systems**, the primary processor for numerous NASA missions, including the **Curiosity and Perseverance Mars rovers** and the **James Webb Space Telescope**. **PIC64** was designed to achieve a 100-times improvement in performance per watt compared to NASA's current space-qualified computers. Additionally, **X280 vector extensions** that enable **artificial intelligence** and **machine learning workloads** should allow spacecraft to operate farther from Earth with greater autonomy. Microchip plans to build two versions of the chip: the **radiation-hardened PIC64-HPSC1000** for medium and geosynchronous Earth orbits and deep space and planetary missions, and the **radiation-tolerant PIC64-HPSC1100** for low-Earth orbit.

In July, **Meta Platforms Inc.** of California introduced **Llama 3.1**, a state-of-the-art, open-source **large language model** that could potentially transform the aerospace industry. Building upon its predecessor, Llama 3.1 has the ability to be fine-tuned with aerospace-specific data, enabling a wide range of applications. Pre-trained on vast amounts of information, such models significantly reduce the computational resources and amount of time required for training, making them cost-effective and environmentally sustainable. The open-source nature of Llama 3.1 allows organizations to customize the model within their own secure computing environments, ensuring that sensitive information remains protected. Open-source models such as **BERT and RoBERTa** are already used in the aerospace requirements engineering domain, while **generative AI** models like **GPT-3.5-turbo** have demonstrated significant potential for enhancing accident and incident analysis by processing extensive textual reports found in accident and incident databases to extract safety lessons. These models could also power advanced pilot assistance technologies, enabling natural language interaction with avionics, real-time analysis of in-flight communications to detect anomalies and improved maintenance support through natural language queries. Such advancements are predicted to significantly enhance safety, efficiency and reliability within the aerospace industry. ★

▼ NASA's Voyager 1 probe in June resumed normal transmission from its four of its science instruments. Transmissions were disrupted in November 2023 by what engineers at the NASA-funded Jet Propulsion Laboratory later determined was due to the failure of a single memory chip in one of Voyager's onboard computers.

NASA/JPL-Caltech



Advancing technologies for safety-critical applications

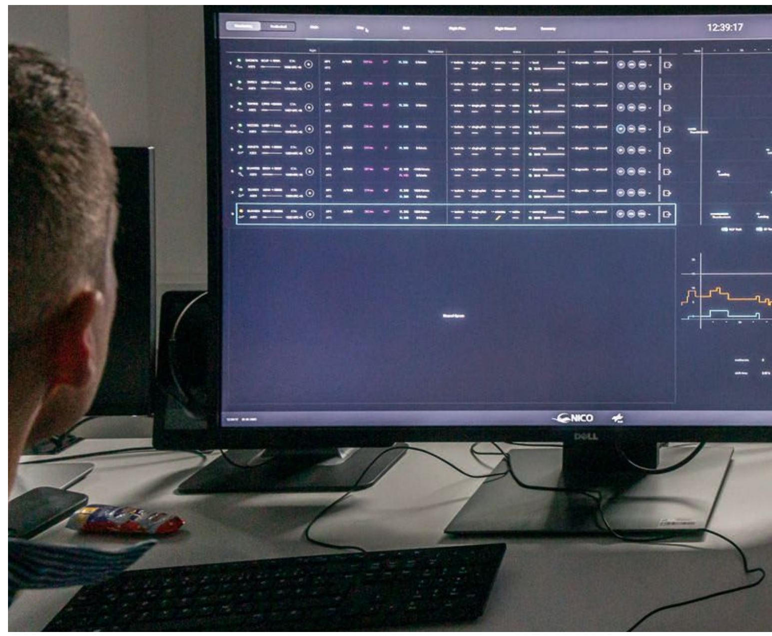
BY TIMOTHY ETHERINGTON, SHERRY YANG AND BERND KORN

The **Digital Avionics Technical Committee** advances the development and application of communications, navigation and surveillance systems used by military and commercial aircraft.

The global community of **avionics suppliers** is leading the application of the latest technologies for real-time, safety-critical embedded systems, as evidenced by several industry-changing innovations this year.

In May, **Boeing** and **AOSense** of California completed the world's first flight test of quantum sensor technology for navigating independent of GPS. The four-hour flight from **Lambert International Airport** in St. Louis demonstrated that the quantum sensors performed as required during takeoff, landing and flight maneuvers. With a **six-axis quantum inertial measurement unit**, or IMU, researchers mechanized a strap-down inertial navigation system on a **Beechcraft 1900D**. The IMU consists of three quantum inertial sensors that measure the accelerations and rotations about each axis of the airplane. A quantum sensing technique called **atom interferometry** detects rotation and acceleration, resulting in unparalleled accuracy without a GPS reference. AOSense designed and built the IMU in collaboration with Boeing, and Boeing integrated the IMU with other sensors and signal processing electronics to create this first-of-its-kind quantum navigation sensor. The flight demonstrated the potential for quantum sensors to provide reliable navigation in **GPS-denied environments**.

In June, testing was completed with airline transport **pilots in-the-loop** for **NASA's Subsonic Single Aft Engine Electrofan** flight deck. With the SUSAN concept, NASA is assessing the means of reducing carbon emissions by 50% while retaining the size, range and speed capabilities of large regional aircraft. SUSAN is a 180-passenger aircraft design with a single aft-turbine and 16 electric engines, eight on each wing. For the flight deck, designed by **NASA's Langley Research Center** in Virginia, there is a single throttle and reliable full-authority autothrottle, since a throttle for each engine would be unwieldy. Automation with pilot concurrence is used to manage engine failures. Electronic engine controllers ensure turbine-engine limit protection and recommend engine shutdown as required. Thrust is managed according to a single performance target to enable a single throttle and thrust dial during normal operations, with digital indications of turbine fan speed and exhaust gas temperature. Secondary engine parameters are displayed to indicate abnormalities. Core speed and oil pressure and temperature are displayed for the turbine engine, and thrust bars with color and shape codes are displayed to indicate electric engine failures. An electric engine synoptic page provides visual continuity between the engine-display secondary parameters and the power generation and distribution of the thrust produced by each electric engine.



▲The German Aerospace Center, DLR, continued to evaluate its remote co-pilot or RCP, a station for simultaneous remote monitoring up to eight aircraft flights. The monitored flights are listed to the left of the screen, and at the bottom right is a timeline of upcoming tasks for each.

German Aerospace Center

The **German Aerospace Center, or DLR**, continued to study technologies for improving the efficiency and safety of commercial aircraft. In April, professional pilots tested DLR's **remote co-pilot**, an intelligent station with which pilots and other personnel on the ground monitor flight data, help potential operational issues and provide real-time support to pilots in the air. RCP, created under the **Next Generation Intelligent Cockpit research project**, was designed to make **single-pilot operations** possible by reducing the workload of a midflight pilot and ensuring continuity in operations during emergencies. With the RCP workstation, up to eight aircraft can be monitored simultaneously, with emphasis on ensuring immediate, one-to-one support in emergency situations. The rigorous testing by pilots showed the potential for such technologies to improve aviation safety, and the international research community recognized the value of the research in November by conferring this year's **Red Dot Design Award** to the design of the RCP user interface. ★

Contributor: *Mark Darnell*

Pairing AI with human-machine teaming for the next step forward

BY NICHOLAS NAPOLI AND CHRISTOPHER TSCHAN

The **Human-Machine Teaming Technical Committee** fosters the development of methodologies and technologies that enable safe, trusted and effective integration of humans and complex machines in aerospace and related domains.

The Air Force Research Laboratory's XQ-67A demonstrator made its first flight in February, from Gray Butte Field Airport, Palmdale, California. The remotely piloted drone is the first in a series for testing the pairing of autonomous drones with human-piloted fighter jets.

Air Force Research Laboratory

Because of its potential to revolutionize aerospace, **artificial intelligence** was the topic of the year. In the near term, AI could be the means of enhancing autonomy in aerospace operations. Integrating AI with **human-machine teaming, HMT**, is another logical step forward. There are various ways to conceptualize HMT, but the approach that emerged this year consists of a machine that works alongside humans, monitors their performance to reduce workload and in some cases serves as a reliable wingman.

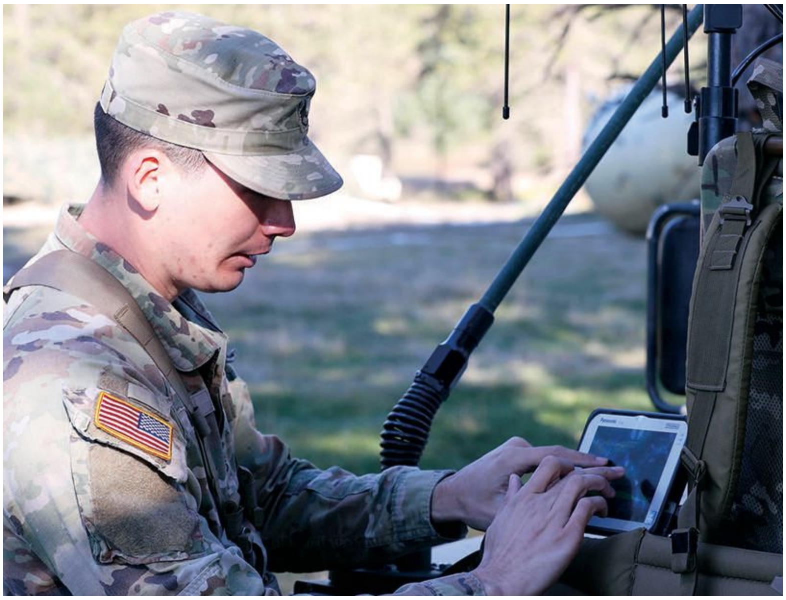
One area that will require HMT is developing the next generation of **extravehicular activity spacesuits**. In June, **Axiom Space** of Texas, in partnership with **SpaceX** and **NASA**, completed the first pressurized simulation with its next-generation **Axiom Extravehicular Mobility Unit** suit — the first such test since the Apollo era. Two NASA astronauts are to don AxEMU suits when they venture onto the lunar south pole during the **Artemis III** landing, scheduled for 2026. In August, **Nokia** and **Axiom** partnered to integrate high-speed cellular networks into the AxEMU suits, so that high-definition video, telemetry and voice can be transmitted across several kilometers on the moon.

In September, SpaceX's own EVA suit was tested for the first time during the **Polaris Dawn** private spaceflight. Billionaire Jared Isaacman and SpaceX engineer Sarah Gillis partially exited their Dragon capsule, performing the first privately funded "stand up EVA." For future flights, these suits must team with the astronauts to learn and predict an astronaut's biometrics while simultaneously monitoring the space environment to ensure astronaut safety. The suits will also need to assist the astronaut in capturing and processing exploration data.

In the realm of military flight, the **U.S. Air Force Research Laboratory** in February conducted the first flight of the **XQ-67A**, built by **General Atomics**. This remotely piloted demonstrator represents the second generation of autonomous, collaborative aerial platforms that could serve as "loyal wingman" drones for the **Next Generation Air Dominance** sixth-generation fighter jet. General Atomics in April said that the XQ-67A is a prototype for its **Collaborative Combat Aircraft**. The XQ-67A flight tests are focused on autonomy, human systems integration, sensor and weapons payloads, and networks and communications — all components of HMT. Airbus is also developing loyal wingmen drones to team with Eurofighters.

In February, the **U.S. Air Force** added an **automatic ground collision avoidance system** to the **Boeing T-7A Red Hawk** trainer. AGCAS is designed to take control of the aircraft when the pilot passes out, such as when experiencing high g-forces — a good example of HMT in which the machine is working to keep the aircraft and pilot safe.

Another potential application of HMT is reducing the size of flight crews. In May, the **European Union** completed a technical milestone with **DARWIN, the Digital Assistants for Reducing Workload and Increasing Collaboration** project to develop AI-based automation for cockpit and flight operations. Researchers completed an AI-reasoning assessment based at technology readiness level 5. ★



Integrated decision-making with distributed operations continues to shape the future

BY ALI RAZ AND STEPH COPEY

The **Information and Command and Control Systems Technical Committee** fosters a system-of-systems perspective on the conception, implementation and sustainment of information and command and control systems in support of national security, aviation and space missions in public and private sectors.

▲ The U.S. Army's 1st Multi-Domain Task Force completed an exercise in July with Collins Aerospace technology that allows soldiers to create mobile operations centers. Among the tasks, they demonstrated that the unit could maintain connectivity in a moving vehicle.

Collins Aerospace

This year saw the fruition of ambitious **command-and-control technology development programs** that started years ago. Information, machine learning and ubiquitous data have played critical roles in decentralizing the command-and-control architectures traditionally operated under a centralized command paradigm since their inception.

In February, the **Combined Joint-All-Domain-Command-Control program** completed its first major milestones toward initial operational capability. **CJADC2** aims to connect C4ISRNET systems — those related to command, control, communications, computers, intelligence, surveillance and reconnaissance — across the domains of all U.S. military and potentially coalition services to facilitate integrated information and decision-making advantages. In this way, CJADC2 manifests a major shift in traditional command-and-control systems as information, harnessed through **artificial intelligence and machine learning**, helps connect geographically distributed systems for strategic and tactical decision advantages. In March, **Deputy Secretary of Defense Kathleen Hicks** witnessed an operational demonstration of CJADC2 during a multinational event at the Army's National Training Center at Fort Irwin in California. This illustrated the technology's transformational impact in current and future battlespaces.

Outside the test and evaluation environment, ongoing conflicts in the Middle East gave the public a rare glimpse of integrated command-and-control system technologies at work. In April, a vast volume of airspace across the Middle East was restricted from routine use when Iran launched a series of **drone attacks** on Israel. These attacks were countered by an assortment of defenses from the United States, Israel and Jordan that functioned together in a well-coordinated manner. The success of this joint defensive mission can be attributed to information-sharing via distributed integrated command-and-control system technologies.

The theme of **integrated decision-making amid distributed operations** through data, AI and machine learning was evident in other command-and-control modernization pursuits this year. In April, Kevin Murray, chief technology officer for the U.S. Marine Corps, introduced **Project Dynamis**, the Marine Corps' contribution to the CJADC2 program that revolves around software modernization. In May, the **Air Force Research Laboratory** released the broad agency announcement, **"Coordinating Austere Nodes through Virtualization and Analysis of Streams."** With this CANVAS program, the laboratory aims to leverage **intent-based networking concepts** to autonomously connect distributed systems that can continuously orchestrate and execute command-and-control solutions in contested environments with high attrition.

Additionally, **Collins Aerospace** in July demonstrated its **Next Generation Battle Management on The Move**, an agile, distributed command-and-control concept it is developing for the **U.S. Army**. In this **mobile operations center**, AI and machine learning technologies assist operators with battle management by quickly sorting and integrating data from various sources in the battlespace while enhancing the survivability and reliability of the command-and-control operation. In September, the **U.S. Army Science Board** released a request for information regarding **data-centric command-and-control**, seeking state-of-the-art solutions on metrics to evaluate the future distributed command-and-control operations. The RFI also requested the submission of strategic approaches for holistic data-centric understanding across domains.

This year demonstrated strong demand for enabling integrated command-and-control technologies in the aerospace and defense communities. Such technologies are the glue that bring together distributed complex systems for achieving demanding missions. With many projects in the works, the years to come are poised to bring more developments in information and command-and-control systems. ★

Advances made in the development, testing and certification of AI-based aerospace sensing and control

BY KERIANNE HOBBS

The **Intelligent Systems Technical Committee** works to advance the application of computational problem-solving technologies and methods to aerospace systems.

▲ An autonomous robot assembles a truss structure at NASA's Langley Research Center in January. Under this Precision Assembled Space Structure project, researchers are working toward a ground demonstration of autonomous assembly of a space telescope.

NASA's Langley Research Center

This year saw notable demonstrations of **artificial intelligence** and **intelligent robotics** for air and space, as well as progress toward certification of AI-based aerospace systems.

In January, the **Aerospace Corp**. in California demonstrated a new approach for **pose estimation** and imagery from **ExoRomper**, its in-space machine vision testbed aboard the **Slingshot-1** small satellite. The ExoRomper imagery was analyzed with Aerospace Corp.'s **BetterNet** method, designed to be a watchdog for autonomous systems with **AI and machine learning algorithms**. Once added to existing deep networks, BetterNet can assess if predictions from an AI model are based on sufficient training support and validation data to be trustworthy. In this initial demonstration, BetterNet was able to catch nine out of 10 bad pose estimates. The Aerospace Corp. has made ExoRomper's in-space imagery and data labels freely available on its website.

In January, **NASA's Langley Research Center** in Virginia demonstrated **autonomous robotic assembly** under the **Precision Assembled Space Structure project.** Here, researchers have developed and tested autonomous systems to drive robotic manipulators to join structural modules. This includes a **trajectory generation system**, a **vision-based pose estimation algorithm** for fine alignment and software to control the end-effector tools.

The January test consisted of retrieving two 2.8-meter tall truss modules and joining each to another module on a test stand, the first step toward a planned full-scale ground demonstration of autonomously assembling the backbone truss structure of a telescope. It also marked the first test conducted in NASA Langley's new full-scale **In-Space Assembly Laboratory**.

In April, **DARPA** announced completion of first AI versus human dogfight, conducted between the AI-piloted **X-62A VISTA** test aircraft and a human-piloted **F-16**, as part of its **Air Combat Evolution program**. Across 21 test flights from Edwards Air Force Base in California, some 100,000 lines of software were changed to test and refine AI-agent performance, including defensive and offensive maneuvers. The AI-controlled X-62 maneuvered within 610 meters of the F-16 at closure rates up to 1,931 kph. In addition, the team showcased effective ethics and safety procedures by incorporating ground and aerial collision avoidance measures as well as combat training rules.

In June, **GE Aerospace** submitted a report to **FAA** documenting the first recorded attempt at generating certification evidence for AI-based digital aerospace systems using the **Overarching Properties** framework. NASA, FAA and other agencies are evaluating the OPs for developing an alternate means of compliance to streamline the certification process. The GE report described promising results and experiences that could help FAA shape future policies for certifying AI-based systems, which is not supported by existing standards such as DO-178C. GE also publicly released a tool on GitHub for generating OP-based assurance cases.

In June, the **Local Intelligent Networked Collaborative Satellites Laboratory** of the **AIr Force Research Laboratory's Space Vehicles Directorate** integrated autonomy software, showcasing collaborative inspection under the AFRL seedling **Safe Trusted Autonomy for Responsible Spacecraft** program. Specifically, the laboratory evaluated algorithms developed using **reinforcement learning** as the decision-maker, coupled with run-time assurance to maintain safe behaviors, and then the outputs were displayed on a human-autonomy interface for operator interactions and aerial platform emulation.

The LINCS lab is creating an environment for testing multisatellite close-proximity operations, using aerial vehicles as emulation platforms. Established in 2022, the lab aims to provide a testing environment to allow academia, industry and other government agencies to test algorithms and software in an operationally relevant environment. ★

Contributors: *Anthony Aborizk, Benjamen Bycroft, John R. Cooper, Saswata Paul and Sean Phillips*

Quantum sensing moves closer to reality

BY IVAN PETRUNIN AND NICHOLAS J. NAPOLI

The **Sensor Systems and Information Fusion Technical Committee** advances technology for sensing phenomena, fusion of data across sensors or networks, and autonomous collaboration between information systems.

▲ Boeing in May demonstrated continuous operation of a quantum sensor during a four-hour flight test from St. Louis Lambert International Airport. Such technology is one method under evaluation for ensuring that aircraft and spacecraft have continuous access to navigation information in the event of a GPS outage.

Boeing

New sensing systems and continuing improvement of the performance and intelligence of fusion solutions dominated this year's research and development headlines.

In August, **Northrop Grumman** announced it completed the first flight test campaign of its **Electronically Scanned Multifunction Reconfigurable Integrated Sensor**. Designed to work simultaneously as a radar, electronic warfare and communication system, this sensor is based on a **fully digital active electronically scanned array** and an easily scaled and reconfigurable architecture for applicability across platforms and domains.

A series of demonstrations of quantum sensor systems was conducted worldwide. In January, the **U.K. Royal Navy** worked alongside quantum technology experts on experiments aiming to improve the performance and security of **positioning and navigation** solutions at sea. In the last round of testing, the quantum accelerometer technology was taken aboard the U.K.'s Ministry of Defense cargo ship to evaluate how it would perform under the real-life conditions of ship vibration and motion as a step toward implementing quantum sensing for navigation. Researchers conducted several tests that indicated quantum sensors could soon enable precise and safe navigation for defense and commercial applications in the event there is a disruption with **GPS** and other navigational systems.

In May, **Boeing** flew a six-axis **quantum inertial measurement unit**, developed in collaboration with the California-based company **AOSense**, aboard a **Beechcraft 1900D**. Also in May, the "ultra-cold-atom-based" navigation system built by U.S. company **Infleqtion** completed an eight-hour flight from Boscombe Down in the U.K. aboard an **Avro RJ100**, a short-haul commercial flight. The U.K. has pledged to deploy quantum navigation systems on all its commercial aircraft by 2030.

In September, **Eutelsat America Corp.** of Washington, D.C., and **OneWeb Technologies** of Texas began consumer sales of their software-defined outdoor receiver, **Astra**. The receiver provides users with enhanced situational awareness and resilience to global navigation satellite system outages via integration with **alternative position, navigation and timing services** such as Iridium's.

In March, the **European Space Agency** awarded contracts to consortiums led by **Thales Alenia Space** and **GMV Aerospace and Defence S.A.U.** for the development of low-Earth orbit constellations that can provide end-to-end PNT services. The teams comprise some 50 entities from 14 countries representing a combination of space primes and small- and medium-sized businesses. The deliverables include five satellites, ground and user segments, as well as experimentation and service demonstration in different industries' representative user environments. The planned demonstrations join existing research projects and experiments aimed at overcoming the vulnerability of existing GNSS-based solutions.

In January, **Texas Instruments** at the Consumer Electronics Show introduced the new **millimeter-wave radar chips** supporting satellite radar architectures. With the design, higher levels of autonomy are possible due to improved sensor fusion and decision-making in advanced driver assistance systems. TI called this semiconductor the first single-chip radar sensor designed for satellite architectures that allows developers to use 360-degree sensor coverage and sensor fusion algorithms.

In May, **Lattice Semiconductors** of Oregon presented at the Embedded Vision Summit a new **3D sensor fusion reference design** for autonomous application development. The design enables enhanced perception, reliability and improved decision-making with advanced 3D sensing delivered by the new solid-state lidar design, as well as with artificial intelligence-supported synchronization and sensor fusion for lidar, radar and camera sensors. ★

Engineers drive fixes to Voyager 1 spacecraft and CrowdStrike software

BY STEVEN LINCOLN

The **Software Systems Technical Committee** focuses on software engineering issues for complex and critical systems, including requirements, design, code, test, evaluation, operation and maintenance.

In April, the **Voyager 1** spacecraft resumed transmission of science and engineering information, two days after mission controllers at **NASA's Jet Propulsion Laboratory** in California sent a software fix to the spacecraft. JPL announced in November 2023 that Voyager, launched in 1977 and now traveling beyond our solar system, stopped sending "readable" data. Engineers later discovered the cause: a stuck bit in a chip that stores part of the memory of the **Flight Data Subsystem**, one of the spacecraft's three onboard computers.

The software fix was created by a tiger team at JPL that systematically evaluated each subsystem on the spacecraft via a dependency bone chart until the failure was identified, a task made more difficult by the fact that "almost every engineer and programmer who helped build Voyager have either retired or passed away," the Pasadena Star-News reported in March.

"So, a lot of what the tiger team has had to do is go back and look through old documentation," Suzanne Dodd, Voyager project manager, told the newspaper. "Try to recreate how the code was done and why the code was done that way."

Their solution was to divide the code into sections and store them in different places within the Flight Data Subsystem. The code sections were then adjusted so they worked seamlessly as a whole.

In July, one of the biggest unintentional software mishaps in history occurred, when a **CrowdStrike** Falcon Sensor security software update caused global system crashes. The outages were due to a defect in the Rapid Response Content, which went undetected during validation checks. When the content was loaded by the Falcon sensor, this caused an out-of-bounds memory read, leading to Windows crashes and the so-called blue screen of death. CrowdStrike released an update the same day as the outage that resolved the issue, and Microsoft provided instructions on how to remediate the problem ahead of the deployed fix. CrowdStrike published a root cause analysis in August that cited validation techniques, logic and valid data checks, and the company's staged deployment approach as contributors to the crash.

Decades ago, software was considered an add-on to aerospace hardware systems. Today, however, software is recognized as an essential mission enabler that controls ground- and space-based operations of extraordinary complexity. This vital role escalates the impact of software failures. The CrowdStrike failure reportedly cost **Delta Air Lines** alone some $500 million in lost revenue, with its impact on other aerospace organizations still being assessed as of October. Such economic and reputational losses place increased emphasis on capabilities to verify correct functioning of critical software.

In May, the **International Organization for Standardization** and the **International Electrotechnical Commission subcommittee on System and Software Engineering** established an ad hoc group to evaluate the need for international standards on **low-code/no-code software** development at its biannual plenary in Berlin. The industry-specific functionalities of low-code application platforms allow users to create custom solutions for their unique needs. "The global low-code/no-code market is expected to see a compound annual growth rate of 22.7% from now until 2027," according to a March blog post by BP3 Global, an Austin consulting firm specializing in intelligent automation. "At that time, it's projected to be worth $86.9 billion." Also, low-code tools are estimated to "account for over 70%" of all software development by 2025.

Artificial intelligence continued to be broadly explored for aerospace operations, but questions remain regarding whether AI providers can use copyrighted material to train their products. Among the pending lawsuits on this issue is one by the **New York Times**, which in late 2023 sued **Microsoft** and **OpenAI** for using millions of Times articles to train **ChatGPT** and other AI-based products. ★

▼ Members of the Voyager flight team at NASA's Jet Propulsion Laboratory in California in April celebrate the Voyager 1 probe resuming normal transmissions. A tiger team at JPL worked on a software fix for five months.

NASA/JPL-Caltech

Powering missions to Earth's moon and other planetary moons

BY GIANG LAM AND JEREMIAH MCNATT

The **Aerospace Power Systems Technical Committee** focuses on the analysis, design, test or application of electric power systems or elements of electric power systems for aerospace use.

NASA is funding concepts for electrical power generation of a future lunar power grid under its **Vertical Solar Array Technology (VSAT)** and **Fission Surface Power** projects. In January, NASA wrapped up phase one of FSP, in which three contractors created concepts for small **nuclear fission reactors** for future demonstrations on the lunar surface. The reactors were to be designed to stay under 6 metric tons in mass, with the ability to produce 40 kilowatts of electrical power and operate for 10 years. "In the U.S., 40 kW can, on average, provide electrical power for 33 households," NASA said in a press release. The solicitation for phase two is planned for next year, with results of the phase one studies guiding the requirements for the final reactor.

In July, **Astrobotic** of Pennsylvania began thermal vacuum testing at NASA's Johnson Space Center in Texas to demonstrate vertical deployment of its **VSAT concept**. In phase two of the project, scheduled to conclude in December, Astrobotic, Honeybee and Lockheed Martin were tasked to design and develop **10 kW-size solar arrays** and deploy them vertically in a vacuum to simulate lunar gravity, one-sixth that on Earth's. Other VSAT requirements include stable deployment on uneven terrain, autonomous retraction to enable system mobility and surviving the long duration of cold lunar nights.

In the area of lunar exploration, **JAXA, the Japan Aerospace Exploration Agency**, in January landed its **Smart Landing for Investigating Moon** on the lunar surface. Astrobotic's **Peregrine** lander was launched in January and Texas-based Intuitive Machines' **Odysseus** lander was launched in February on the inaugural missions funded by **NASA's Commercial Lunar Payload Services program**. Only Odysseus made it to the lunar surface, though the lander tipped over shortly after touching down.

In September, **NASA's Lunar Trailblazer** spacecraft completed environmental testing. The 200-kilogram spacecraft will be powered by two deployable solar arrays that provide 280 watts of electrical power. Part of the agency's **Small Innovative Missions for Planetary Exploration program,** Lunar Trailblazer with its two scientific instruments is to map the distribution of water on the lunar surface. Lunar Trailblazer is scheduled to be launched as a secondary payload with Intuitive Machines' second lunar lander in early 2025.

NASA also advanced plans to explore the moons of other planets. In April, the agency announced that its **Dragonfly** mission to **Titan**, Saturn's organic-rich moon, has been approved to complete the final design, construction and test of the spacecraft. Planned to be launched no earlier than 2028, the Dragonfly spacecraft is a **quadcopter drone** with eight rotors and will be roughly the size of the largest Mars rover. Dragonfly is being designed to fly for approximately half an hour at a time and travel up to 10 kilometers on a single battery charge, powered by a **radioisotope thermoelectric generator** producing 70 W nominally.

In October, **NASA's Europa Clipper** spacecraft was launched to begin its 5.5-year journey to **Europa,** one of Jupiter's icy moons. The spacecraft is equipped with solar arrays designed to produce 20 kW at Earth and 700 W at Europa. With the solar arrays deployed, the spacecraft spans some 30.5 meters. Once in orbit around Jupiter, Clipper is to make some 50 **flybys** into Europa's atmosphere to study the moon's icy ocean, composition and geology. ★

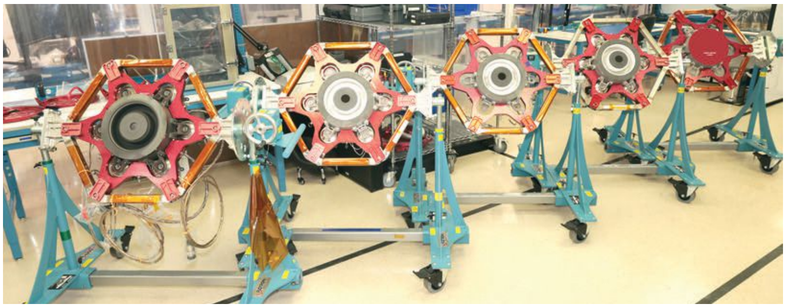
▼ Technicians at NASA's Kennedy Space Center in August finished stowing each of Europa Clipper's 14.2-meter-long solar arrays. Clipper was launched in October and is scheduled to arrive in orbit around Jupiter in 2030 to begin flybys of Europa.

NASA/Frank Michaux

A year of sustained growth and learning about electric thrusters

BY PATRICK "PADDY" NEUMANN

The **Electric Propulsion Technical Committee** works to advance research, development and application of electric propulsion for satellites and spacecraft.



▲ The 12-kilowatt Hall Effect thrusters that Aerojet Rocketdyne is testing for NASA's planned lunar station, Gateway, are pictured here at the company's factory in Redmond, Washington. Two of the thrusters are for testing, and the other three are to be installed on Gateway's Power and Propulsion module to help propel the station in its highly elliptical lunar orbit.

Aerojet Rocketdyne/Jack Fisher

In April, **Busek's BHT-6000** thruster passed environmental qualification, while **Aerojet Rocketdyne** completed acceptance testing for its 12-kilowatt **Hall Effect thrusters, or HETs**. Both designs are to propel the **Power and Propulsion Element** of NASA's planned **Gateway** lunar station.

Also in April, NASA completed initial checkout of the HETs aboard its **Psyche** spacecraft and began cruise operations with the thrusters. As of August, they had operated nominally for some 2,500 hours.

In September, Busek shipped its 250th **Busek BHT-350** thruster. As of October, 100 of them were operating in low-Earth orbit aboard **OneWeb** broadband satellites.

In qualification news, the 1-kW-class **Magnetically Shielded Miniature Hall thruster** designed by **NASA's Jet Propulsion Laboratory** qualified to 8,254 hours in August, while its **H10 HET** demonstrated thermal steady-state operation up to 15 kW, reaching thrust efficiencies exceeding 70%. As of November, Northrop Grumman's sub-kilowatt **NGHT-1X Hall thruster** demonstrated 9,400 hours and 1.5 meganewton-seconds total impulse. Northrop Grumman has six flight units in production for a 2025 delivery.

In April, **Georgia Tech** researchers published the results of their study, in which they fired an **incoherent laser Thomson scattering system** to noninvasively measure electron density, electron temperature and azimuthal electron drift velocity in HETs with high spatial resolution. This experiment provided new details into the physics of HETs, such as detecting nonisothermal magnetic field lines, contradicting traditional models.

In alternate propellant work, researchers at **CNES, the French space agency**, in March investigated water vaporization in microgravity aboard the AirZeroG aircraft. While water-fueled electric propulsion systems have previously flown, this is the first in-depth study of their performance.

Neumann Space of South Australia operated its **ND-15** thrusters aboard the SpIRIT and Skykraft 3 missions over several months, the first time a molybdenum-fueled design was fired on-orbit.

As of June, **ENPULSION** of Lower Austria sent some 200 **Field Emission Electric Propulsion thrusters** to orbit, with multiple indium-fueled units accumulating over 1,000 hours of active thrust-operations time.

In January, **George Washington University** researchers received a **DARPA** grant to continue development of their thruster that achieves beam neutralization via positive and negative ions derived from low-pressure air. They tested this thruster at various pressure conditions, determining that it is most suitable for 80-100 kilometers altitude.

In January, doctoral students at the **Universities of Surrey and Southampton** in the United Kingdom validated a new **inverted pendulum thrust balance** against a well-characterized torsional thrust balance. An external discharge Hall thruster was the test article.

In March, students from the **Rose-Hulman Institute of Technology** in Indiana presented a paper at the IEEE Aerospace Conference on achieving ignition with a **gridded-on thruster**, the first of its kind designed and tested by an all-undergraduate team.

In September, the **Japan Aerospace Exploration Agency** confirmed the completion of a hot-fire test campaign validating a 6-kW-class Hall thruster subsystem and flight-proven Hall thruster subsystem. The components were integrated into the **Engineering Test Satellite-9**, scheduled to launch in 2025.

Nuclear-electric research and development continued. In May, the **Accelerating Space Science with Nuclear Technologies workshop**, held in Arizona, brought together leading experts to discuss new capabilities provided by long-life, high-power electric thrusters. Feedback included requirements for reducing spacecraft transit time for outer planet missions and increased maneuvering capability at the destination. As part of **NASA's Space Nuclear Propulsion Project**, JPL, Princeton University and NASA's Glenn Research Center in Ohio continued developing **high-power, lithium magnetoplasmadynamic thruster** technologies for crewed Mars missions. Current work is focused on testing a 200 kilowatt-electric, steady state, self-field thruster while designing a higher-power, 500-kWe engine. ★

Contributors: *Moe Ahmed, Jack Fisher, Rich Hofer, Wensheng Huang, Akira Kakami, David Krejci, Stephane Mazzouffre, Ishaan Mishra, Alex Nikrant, Kurt Polzin, James Szabo, Anmol Taploo, Mitchell Walker and Hiroki Watanabe*

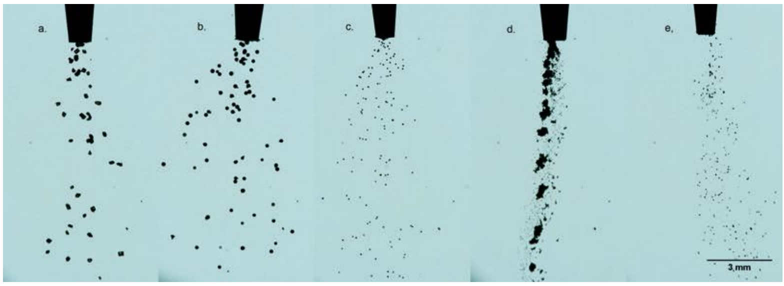
READ THE APPRECIATION

MARIANO ANDRENUCCI, A PILLAR OF THE EUROPEAN ELECTRIC PROPULSION COMMUNITY

Updated standards for explosive devices and other breakthroughs

BY JOHN F. ZEVENBERGEN

The **Energetic Components and Systems Technical Committee** provides a forum for the dissemination of information about propellant and explosive-based systems for applications ranging from aircraft to space vehicles.



▲ Purdue University researchers this year studied surrogate powders for energetic materials, including solid rocket propellants. With high-speed camera photos like this one, they observed and measured how changing the voltage of a motor and size of a nozzle would affect the trajectories of these powders.

Purdue University

In January, researchers from **Purdue University** in Indiana presented at **AIAA's SciTech Forum** their study on how **multi-material 3D printing** changes the mechanical properties of **propellant surrogates** with a new ultraviolet-curable binder. After controlling for time and spatially varying UV irradiance, they concluded that the specimens did preferentially break at the interface, which is promising for producing multi-material structures.

Also in January, **Karman Space & Defense** of California completed the first full-system test of its **descent parachute mortar** for **NASA's Dragonfly mission** to Titan. Karman leveraged decades of experience in pyrotechnic-based mortar systems for human and exploratory spacecraft to address the challenges posed by Titan's harsh conditions. Among them, the Dragonfly quadcopter must operate within surface pressure 1.5 times that of Earth's and survive methane clouds and rain in temperatures below minus 150 degrees Celsius. These conditions also make it more challenging to deploy and operate the parachute that controls Dragonfly's initial descent toward Titan's surface. The test campaign included **simulating thermal, pressure and dynamic environments** that Dragonfly would experience during launch, space flight and on Titan's surface. As needed, engineers conducted proprietary analyses with models based on results of previous missions to verify performance of the parachute motor, which is considered mission-critical hardware. Design updates based on refined mission parameters were completed in the middle of the year, and testing is ongoing.

In July, researchers from **Purdue University** presented research on **energetic processing methods** at the International Pyrotechnic Society Seminar. The researchers observed the **flow of surrogate powders** via high-speed camera as a function of motor voltage and nozzle size. Understanding the role these factors play on the dynamics of powder flow is critical to ensure high-precision deposition. They also developed and characterized a new method for making a molding powder, with 90% sugar by weight using **hydroxyl-terminated polybutadiene**. This new processing approach could be a much faster method to tune the properties of **plastic-bonded explosives**.

In January, the Energetic Components and Systems Technical Committee completed updates to its standard, **"Criteria for Explosive Systems and Devices on Space and Launch Vehicles."** Published in late 2023, the document established criteria for engineers and contractual professionals for design, manufacture and performance certification of explosive systems and explosive devices commonly used on space vehicles and on uncrewed launch systems. The requirements in the standard are intended to serve as a universal set of tools for explosive device manufacturers and application specialists during all phases of development and certification. The committee initiated the effort in 2020 to update its previously published standards in 2005, 2016 and 2018.

Time is a core variable when gathering data, yet the influence of history is not considered when analyzing temperature data from **pyrometry**, information about an object's temperature derived from the radiation it emits. In May, researchers from the **Naval Air Warfare Center Weapons Division** and **Texas Tech University** developed a new method of analyzing pyrometry data to assist in studying energy conversion processes in reactive systems. Their method, published in the **International Journal of Heat and Mass Transfer** in August, introduced a specific way of analyzing a sequence of data points collected over a time interval rather than analyzing snapshots of data and reeling them together. What sets this time series approach apart from traditional techniques is that the analysis distinguishes patterns and dependencies otherwise masked. Time series analysis is commonly used to predict the stock market and forecast weather patterns. With advances in sensor technology and the ability to capture gigabytes of data, the time is right to think differently about approaches to interpreting **thermodynamic data**. ★

Contributors: *Igor Altman, Thomas Blachowski, Monique McClain, Michelle Pantoya and Chris Stessing*

Engine industry retains eco-focus as it expands capacity for air travel

BY MICHAEL G. LIST

The **Gas Turbine Engines Technical Committee** works to advance the science and technology of aircraft gas turbine engines and engine components.

▲ Pratt & Whitney and partners tested a V2500 engine on 100% sustainable aviation fuel in March. The V2500 powers the Airbus A320ceo and the Embraer C-390 Millennium.

Pratt & Whitney

Industry demonstrated continued commitment to testing engines with alternate fuels this year. In January, **Turbotech** and **Safran**, both headquartered in France, tested a small turboprop engine on **gaseous hydrogen fuel**. The test in Vernon, France, demonstrated that the **TP-R90** regenerative turboprop could be modified for hydrogen propulsion. In March, the **IAE International Aero Engines** consortium, headquartered in Connecticut, announced it ran a **V2500** engine on 100% sustainable aviation fuel, SAF. The test at the MTU Maintenance Hannover facility in Germany demonstrated the commitment by engine operators to reducing the carbon emissions of their aircraft. In July, **Rolls-Royce** broke ground on an outdoor test stand at **NASA's Stennis Space Center** in Mississippi. In partnership with **easyJet** of the U.K., Rolls-Royce plans to conduct full-scale testing of a **Pearl 15** modified to run on 100% liquid hydrogen fuel. All major engine manufacturers have invested heavily in demonstrating engine operation on alternative fuels, including SAF blends, in support of the industry's goal of achieving **net-zero carbon dioxide emissions** by 2050.

Engine manufacturers are also assessing changes to fuels, engines and flight profiles to reduce **non-CO2 emissions**, such as **nitrogen oxides**, to further reduce the climate impact of civil aviation. In March, **Pratt & Whitney** of Connecticut announced a new study with FAA and other partners to measure non-CO2 emissions from conventional **Jet A fuel** and **SAF**. In June, **Airbus** announced that flight studies with an **A350** aircraft showed reduced **soot particle emissions** and **contrail ice crystal** formation when using 100% SAF, compared to **Jet A-1**. In July, chief technology officers from **Boeing, Airbus, Dassault, GE Aerospace, Rolls-Royce, RTX and Safran** released a joint statement calling for research to quantify properties of non-CO2 emissions and "establish and improve common models for quantifying the effect of aviation on climate."

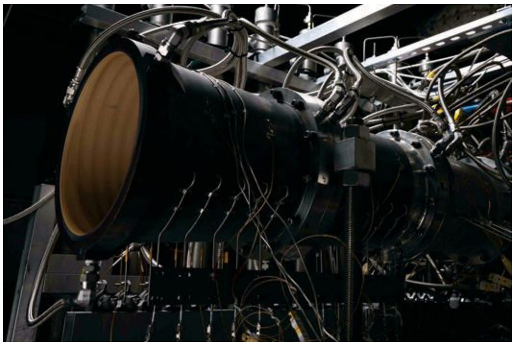
Maintenance, repair and overhaul, MRO, forms a significant sector of the gas turbine engine community in the form of inspecting, testing and repairing engines. Signs of increasing air travel demand arrived in February and March, when **Rolls-Royce** announced an investment of $1.26 billion in product development, including increased capacity for assembly and test of **Trent** engines in Derby, U.K., and Dahlewitz, Germany. In April, **Pratt & Whitney** detailed plans for a new Florida-based **North American Technology Accelerator** for technology insertions, such as inspection and an automated process that support the MRO network. Pratt & Whitney also plans to expand its **geared turbofan engine MRO capacity** by 40% at the **West Palm Beach Engine Center** in Florida. In July, **GE Aerospace** announced a multiyear worldwide $1 billion investment in MRO facilities to meet increasing air travel demand. This includes a significant investment in support of **CFM International LEAP** engines, including a new **Services Technology Acceleration Center** focused on advanced inspection technologies that will decrease aircraft downtime.

Several engine families reached milestones this year. In April, **Rolls-Royce** announced the first flight campaign of a **Pearl 10X** in the company's dedicated Boeing 747 test aircraft. The Pearl 10X will power the **Dassault Falcon 10X**. Also in April, **Honeywell Aerospace** celebrated the **HTF7000** turbofan engine family reaching 10 million flight hours and 20 years of service. **Pratt & Whitney** celebrated the 40th anniversary of the **PW100** engine, which entered service in December 1984. The PW100 powers regional turboprop aircraft and has surpassed 200 million flight hours. ★

High-speed air-breathing propulsion pushes the limits of Mach numbers

BY BAYINDIR H. SARACOGLU, KHALED SALLAM AND FRIEDOLIN STRAUSS

The **High-Speed Air-Breathing Propulsion Technical Committee** works to advance the science and technology of systems that enable supersonic and hypersonic air vehicle propulsion.



GE Aerospace in March began testing a hypersonic dual-mode ramjet. In a press release, the company said the testing took place 11 months after engine development began.

GE Aerospace

High-speed propulsion technologies made strides this year.

In March, **Boom Supersonic** of Colorado completed the first subsonic flight of its **XB-1**, the world's first independently developed supersonic jet, at the Mojave Air & Space Port in California. The XB-1 demonstrator features technologies including carbon-fiber composites, digitally optimized aerodynamics and an innovative propulsion system for efficient supersonic flight. XB-1 completed its fifth subsonic test flight in October, and Boom founder Blake Scholl said the company remains on track to roll out the first of its Mach 1.7 airliners, **Overture**, in 2028 with commercial flights beginning in 2029.

In March, **GE Aerospace** began initial tests of a **hypersonic dual-mode ramjet**, 11 months after the design phase started. The ramjet showed "a threefold increase in airflow compared to previously flight-tested" demonstrators, GE said in a press release. Meanwhile, in Canada, **Space Engine Systems** of Edmonton tested near-full-scale versions of its complete **DASS GNX turbo-ramjet engine** at various air-fuel equivalence ratios in July and August, in order to validate higher-fidelity computational fluid dynamics analyses. Researchers also performed early destruction testing, guiding the incorporation of various cooling methods for improved stability. As of October, integration of the engine into the full-scale **Hello-1 X** demonstrator vehicle was underway. Hello-1 X is designed to operate at 32 kilometers altitude and reach Mach 5.

In Australia, **Hypersonix Launch Systems** and **Rocket Lab** progressed toward the planned flight test of the **Disruptive Autonomous Rapid Transit** hypersonic aircraft. DART is to be powered by Hypersonix's **SPARTAN hydrogen-fueled scramjet engine**, with aerodynamic surfaces for flight control. Plans call for Rocket Lab to launch DART at Mach 7 over the Atlantic Ocean in 2025 as part of the **U.S. Defense Innovation Unit's Hypersonic and High-Cadence Airborne Testing Capabilities Program**.

Since January, the **University of Queensland** in Australia has pioneered inductive and resistive heating of shock tunnel models, including **hydrocarbon fueled scramjet combustors**, in order to fill in a missing piece of the puzzle of fully replicating flight conditions in short-duration test facilities. Such ground tests allow researchers to more accurately model the effects of flight-realistic wall temperatures on system performance and fundamental flow phenomena before they commence with high-cost flight testing.

In April, the **Japan Aerospace Exploration Agency,** JAXA, tested scramjet engines at Mach 6 at the ramjet engine test facility at the **Kakuda Space Center** in Japan. JAXA also conducted scramjet tests adapted for speeds over Mach 8 at **Kakuda's High Enthalpy Shock Tunnel** and component tests for the **Ramjet Engine for High-Mach Integrated Control experiment**.

In Europe, the **Netherlands Organisation for Applied Scientific Research, TNO**, refined its ultrasound burn rate measurement system for **solid -fuel ramjets**. The improved design relies on an innovative post-processing method to convert raw test data into burn rates, enhancing researchers' ability to assess combustor performance during solid-fuel ramjet ground tests. In July, a ground test program in TNO's aeropropulsion test facility was performed to verify the functionality and performance of the improved system.

The Institute of Space Propulsion at the German Aerospace Center, DLR, continued its classic hydrogen fuel test campaigns within the **European Multidisciplinary Design Optimization and Regulations for Low-Boom and Environmentally Sustainable Supersonic Aviation**, or MORE&LESS, project for emissions testing. The upcoming sustainable aviation fuel ramjet emission measurements for this project were prepared in the middle of the year. DLR internal campaigns with a different scope, such as high-temperature material testing for scramjet combustion chamber components and development campaigns for a new and improved injector, completed the year's test schedule. ★

Contributors: *Jesse Kadosh, Joel Malo de Molina, Hideyuki Tanno, Vincent Wheatly and Wolter P.W. Wieling*

▲ German startup HyImpulse Technologies launched its inaugural SR75 sounding rocket in May. The flight was meant to validate technologies for the company's planned orbital rocket, the SL1.

HyImpulse Technologies

Lean, green, self-consuming flying machines: Hybrid rockets soar to new heights

BY TREVOR S. ELLIOTT AND JOSEPH MAJDALANI

The **Hybrid Rockets Technical Committee** studies techniques applied to the design and testing of rocket motors using hybrid rocket systems.

This year saw progress in hybrid rocketry, with key advancements occurring on multiple continents. Combining the benefits of solid and liquid propellants, hybrids continued to make substantial strides in performance, safety and sustainability. This year's milestones included orbital launches, engine development and greener propellants.

In March, **Gilmour Space Technologies** received Australia's first **orbital launch facility license** from the **Australian Space Agency**, clearing the company to launch rockets from its **Bowen Orbital Spaceport** in North Queensland. In November, the company received the launch permit for its three-stage **Eris** rocket, the first time Australia has authorized a commercial orbital rocket launch. Toward that first flight, Gilmour in September completed a wet dress rehearsal, taking the launch countdown to 10 seconds before liftoff. All systems at the launch site operated effectively, and the company in early November said it would announce the launch date for the inaugural flight "in the coming weeks." Should Gilmour succeed, it would position Australia as a key player in the global space industry, with hybrid rockets at the forefront.

Founded in 2018, **HyImpulse Technologies** has rapidly established itself as a competitive player in the hybrid rocket market, with particular interest in the booming **small satellite sector**. In May, the German company launched its inaugural **SR75** sounding rocket, propelled by the company's unique green hybrid propulsion. The rocket lifted off from the **Koonibba Test Range** in Southern Australia on a suborbital trajectory designed to flight-qualify the design HyImpulse's future orbital launcher, **SL1**. Scheduled to debut in 2026, SL1 has three stages driven by the company's **HyPLOX75** motors that burn on paraffin and liquid oxygen.

Maine-based **bluShift Aerospace** this year advanced development of its proprietary **MAREVL** hybrid engine. In September, bluShift completed a **full-duration burn** and **active throttling** of a MAREVL that lasted 60 seconds. This nontoxic hybrid propulsion design has generated considerable interest from the commercial and defense sectors because of bluShift's focus on carbon-neutral biofuel — versatile enough to power suborbital research missions and small satellite launches, as well as the first stages of larger vehicles. If successful, bluShift could transform the small launch industry by providing responsive satellite replacement.

Researchers at the **University of Glasgow** made headlines in January with the test firing of the **Ouroboros-3** engine at the **Machrihanish Airbase MachLab** facility. This **hybrid autophage engine**, or "self-eating" rocket, represents a novel approach to reducing dry mass in launch vehicles. The rocket's polymer fuselage vaporizes during flight, thus contributing to the total propellant mass flowrate while reducing the rocket's structural mass. This technology could revolutionize small launch vehicles by providing a highly efficient, cost-effective solution for launching small satellites into low-Earth orbit.

With these commercial and academic milestones, hybrid rockets could help shape the future of space exploration. ★

Contributors: *Sascha Deri, Michelle Gilmour, Patrick Harkness and Mario Kobald*

Making strides in hybrid powertrain technology

BY JONATHAN S. LITT

The **Inlets, Nozzles and Propulsion Systems Integration Technical Committee** focuses on the application of mechanical design, fluid mechanics and thermodynamics to the science and technology of air vehicle propulsion and power systems integration.

In February, **Ampaire of California** announced the completion of its first ground test in which its **hybrid-electric Eco Caravan demonstrator** ran on 100% sustainable aviation fuel. This retrofitted Cessna Grand Caravan first flew in 2022, its **Pratt & Whitney Canada PT6 turboprop engine** replaced by a 570-kilowatt **AMP-H570 powertrain**. The Eco Caravan is a parallel hybrid, consisting of a diesel-cycle engine with an electric drivetrain that both drive the aircraft's propeller.

In August, the company announced it was preparing for flight tests with 100% SAF. Ampaire anticipates that this conversion will reduce fuel burn and emissions by up to 70%, lower operating costs 25%-40% and extend the range to over 1,100 miles (1,770 km). Once flight tests are complete, the company will perform endurance tests followed by a tear-down of the propulsion system to inspect for effects on the power plant from using 100% SAF.

In September, **Heart Aerospace of Sweden** revealed its Heart Experimental 1, or **Heart X1**, demonstrator, an all-electric aircraft that is to begin remotely piloted flight tests in 2025. Heart X1 is to demonstrate the technology for a planned 30-seat **ES-30 hybrid-electric regional aircraft**. In May, Heart announced modifications to the ES-30 design, including an updated powertrain created from off-the-shelf turboprop engines and electric motors. The earlier design included wing struts, a large battery compartment mounted under the fuselage and a range extension system housed in the rear fuselage comprising twin turbogenerators using SAF — now all gone.

The redesign eliminates the turbogenerators, freeing up that fuselage space for the battery pack, reducing drag and improving crashworthiness, the company says. The new design calls for an **independent hybrid propulsion system**, consisting of small outboard turboprop engines with large battery-powered electric motor systems inboard. The design will enable flights up to 200 kilometers on battery power with the turboprops feathered. The turboprops could be activated to extend the cruise phase, increasing the range to 800 km, similar to the previous design.

In April, **magniX of Washington** completed its first phase of altitude testing of electrified powertrain components at NASA's Neil A. Armstrong Test Facility in Ohio. magniX is developing this powertrain under **NASA's Electrified Powertrain Flight Demonstration** project, and plans call for installing the powertrain in a modified De Havilland Canada Dash 7 for test flights in 2026. For the altitude testing, engineers simulated flight conditions at 27,500 feet to determine whether the powertrain could meet performance objectives in the thinner air and greater temperature ranges at that height.

According to NASA's Brad French, lead systems engineer for the project, such testing is critical for electrified aircraft propulsion technologies because many of the potential problems that a design might encounter only present themselves at higher altitudes. NASA and magniX also investigated the **engine's thermal management system** to determine how heat was transferred throughout the machine. Concurrently, magniX performed baseline flight tests with the Dash 7, provided by Air Tindi, so it can compare fuel savings and performance improvements with the hybrid-electric demonstrator. Those flights were completed in June. ★

▼ Ampaire of California in August said it was preparing to fly its hybrid-electric Eco Caravan with 100% sustainable aviation fuel. The demonstrator is pictured here during its inaugural flight in 2022 from Camarillo Airport near Los Angeles.
Ampaire

A year of firsts in liquid propulsion

BY BRANDIE L. RHODES

The **Liquid Propulsion Technical Committee** works to advance reaction propulsion engines employing liquid or gaseous propellants.

▲ United Launch Alliance in January launched its first Vulcan Centaur, the successor to its Atlas V design. ULA plans to launch up to 10 Vulcans in 2025.

Aerospace America/John Tylko

Government and commercial entities pushed the boundaries of liquid propulsion this year. **SpaceX** flew **Starship-Super Heavy** rockets four times, completing ascent burns on both stages and a soft landing of the Super Heavy booster in June. That flight also marked the first controlled reentry of a Starship, with a flip and burn maneuver before splashdown. In the October test, SpaceX for the first time returned a Super Heavy to the tower, where the 69-meter-tall stage was caught midair by the tower's "chopstick" arms. Starship is the designated lander for NASA's **Artemis III** mission, scheduled for 2026. And in August, SpaceX debuted and test-fired the **Raptor 3**, a 2.74-meganewton **methalox engine** capable of 350 seconds of specific impulse — designed for rapid reuse and to eliminate the need for engine heat shields.

In July, **Boeing** completed the final integrated functional test and delivery of the Space Launch System core stage for NASA's **Artemis II** crewed lunar flyby. Boeing engineers, working closely with NASA, rigorously evaluated the propulsion system, avionics and overall performance of the core stage prior to its delivery to **NASA's Kennedy Space Center** in Florida.

For the Artemis IV landing and beyond, NASA is developing a more powerful SLS variant, **Block 1B**, to carry substantially larger payload mass to the moon. In April, **Aerojet Rocketdyne**, an L3Harris company, completed modernizing and testing the updated **RS-25** engines that will propel the core stage. Updates included modern flight computers to withstand the SLS solid rocket motors' high temperatures. Furthermore, Boeing began production of the **SLS Exploration Upper Stage** at **NASA's Michoud Assembly Facility** in New Orleans. EUS will have four Aerojet Rocketyne **RL10** engines.

In July, **Ariane 6** made its inaugural flight from Europe's Spaceport in French Guiana. The rocket's solid boosters and the revised main stage motor, **Vulcain 2.1**, provided a flawless liftoff. The new upper stage allowed the completion of the commercial part of the mission, with two VINCI upper stage engine boosts and a nominal auxiliary power unit operation. In the demonstration phase, the third VINCI deorbit boost could not be performed. Ariane 6 is developed and produced by **ArianeGroup** on behalf of the **European Space Agency**.

In August, the **German Aerospace Center, DLR**, for the first time tested **LUMEN**, its **liquid upper stage demonstrator engine** at the European research and technology test bed P8.3 in Lampoldshausen, Germany. With LUMEN, a modular methalox bread-board engine in the 25-kilonewton-thrust class, DLR plans to validate technologies that can only be tested in a complete rocket engine.

In January, **United Launch Alliance** completed the inaugural flight of a **Vulcan Centaur**. Vulcan's first stage is powered by two Blue Origin 2.4 meganewton, oxygen-rich **staged combustion BE-4** engines; this was also the inaugural flight of the BE-4. The payload was **Astrobotic's Peregrine lunar lander**, the first mission funded under **NASA's Commercial Lunar Payload Services, CLPS,** program. While Peregrine never reached the lunar surface due to a leak in its propellant tank, the lander circled the moon and executed a controlled reentry in Earth's atmosphere.

In February, **Intuitive Machines** of Texas made history with its lunar lander, **Odysseus** — also funded under CLPS — as the first commercial company to land on the moon, as well as the first U.S. lunar landing since 1972. Odysseus completed its surface objectives, despite tipping over after touchdown. The lander also demonstrated another substantial milestone: the first ignition of a cryogenic engine in deep space. Its deep-throttling, methalox, **VR-900** engine set Odysseus down near the south pole, a region that astronauts are to explore in the **Artemis** crewed landings. ★

Contributors: *Nathan Andrews, Joel Bridges, Colin Cowles, Christoph Kirchberger, Anne Lekeux, Jason Thrasher and Steve Shark*

Interest grows in nuclear propulsion for deep-space transportation

BY BRYAN PALASZEWSKI AND KURT POLZIN

The **Nuclear and Future Flight Propulsion Technical Committee** works to advance the implementation and design of nonchemical, high-energy propulsion systems other than electric thruster systems.

▲ NASA and DARPA are targeting 2027 for their in-space demonstration of nuclear thermal propulsion, shown here in an illustration. Beyond this demonstration, NASA is studying how nuclear propulsion could enable faster transit times to deep-space destinations, including the outer planets of the solar system.

Lockheed Martin

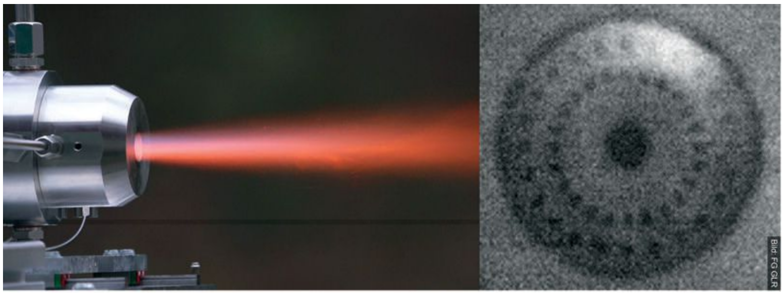
In August, **DARPA and NASA** completed a preliminary design review of their DRACO spacecraft. The goal of the **Demonstration Rocket for Agile Cislunar Operations** program is to demonstrate in-space **nuclear thermal propulsion, NTP**. A **Lockheed Martin-built spacecraft** will be propelled by a nuclear reactor designed and fabricated by Virginia-based **BWX Technologies**. Progress was also made in fuel manufacturing risk-reduction testing, component environmental and functional testing and test article fabrication. Plans call for a **United Launch Alliance Vulcan Centaur** rocket to launch the DRACO spacecraft in 2027. The U.S. Space Force will oversee the launch, referred to as USSF-25.

For missions beyond DRACO, NASA continued to mature NTP technology under its **Space Nuclear Propulsion project.** Funded by NASA and the U.S. Department of Energy, California-based **General Atomics** and **Ultra Safe Nuclear Corp.** of Washington refined **NTP reactor designs**, performed several manufacturing demonstrations of reactor components and executed multiple test and evaluation campaigns in January, March and August. Among the tests, the companies exposed reactor fuel samples to a hot hydrogen gas environment at **NASA's Marshall Space Flight Center** in Alabama, experimenting with various protective materials and features in tests where temperatures were rapidly increased to mimic the operating profile of an NTP engine.

Also under the **Space Nuclear Propulsion project**, the **University of Alabama in Huntsville** in January conducted a wide range of trade studies and sensitivity studies regarding utilizing NTP for robotic missions to the outer planets. This work studied missions to the outer gas giants using an NTP engine with a thrust in the range of 12.5-15 thousands of pounds force. The specific impulse analyses showed that a 13-klbf engine with a specific impulse as low was 850 seconds could propel flagship-class spacecraft to the outer gas giant planets on a **direct-transfer trajectory,** reaching the destination in some cases years earlier than previous missions that used gravity-assist trajectories. A separate study, conducted by **Analytical Mechanics Associates** of Denver, found that a 30-40 kilowatt-electric nuclear electric propulsion-powered spacecraft, possessing a high Earth departure velocity, could deliver a Cassini-sized payload to Saturn on a direct-transfer trajectory in seven years — or in significantly less time if the departure velocity is greater.

In January at **AIAA's SciTech Forum** in Orlando, researchers from **NASA Marshall, NASA's Glenn Research Center and the U.S. Department of Energy** presented a technology assessment for transformational space transportation options. Requested by **NASA's Space Technology Mission Directorate**, the study recommended near-term or sustained investments to make meaningful progress toward maturation for far-term fast transit spaceflight.

In July, NASA analyses of **atmospheric mining in the outer solar system, AMOSS**, were presented at AIAA's **ASCEND** conference in Las Vegas. AMOSS would allow the mining of nuclear fusion fuels from the atmospheres of Uranus and Neptune. In one concept, a nuclear-powered aerospacecraft would cruise in the atmosphere, capturing the helium-3 and deuterium for refinement into fuels that would power fusion rockets to various destinations in the solar system. To assist the mining, nuclear orbit transfer vehicles would be powered hydrogen mined from the water ice on the planet's moons. Capturing the water ice and separating the water ice from the moon regolith are major challenges. For a 100-metric-ton water mining operation, if the water accounts for 75% of a 10-metric-ton payload machine, approximately 14 machines would be needed. Based on past analyses, the water ice fraction on the moons of Uranus could be very high, making mining more efficient. If the mass fraction of water in the regolith is below 10%, many hundreds of machines would be required. ★



Rotating detonation designs make progress on multiple continents

BY SHIKHA REDHAL AND ERIC BACH

The **Pressure Gain Combustion Technical Committee** advances the investigation, development and application of pressure gain technologies for improving propulsion and power generation systems and achieving new mission capabilities.

▲ Between April and June, researchers at TU Darmstadt conducted ground testing of a small-scale rotating detonation engine powered by gaseous hydrogen and oxygen. The goal of the project is to identify an RDE design that produces thrust comparable to today's satellite thrusters.

TU Darmstadt/Henrike Jacob

Advancements this year led to an international expansion of pressure gain combustion research. This was evident at the **13th International Workshop on Detonation for Propulsion** hosted by the University of Michigan in June, which was attended by nearly 100 researchers from around the world. In July, European Commission-funded research into the integration of **rotating detonation engines** began. Organized under the doctoral training network Harnessing Hydrogen's Potential With Rotating Detonation, or H2POWRD, and coordinated by TU Berlin, the program comprises a consortium of 18 international partners.

In February, the **Netherlands Organisation for Applied Scientific Research** tested the first **hydrogen-air RDE** in the Netherlands. The parametric study measured the sensitivity of pressure gain and combustion efficiency to engine geometry, mixture ratio and total mass flow, which provided data for a quasi-1D thermodynamic RDE performance model. The **Institute of Gas Turbine and Aerospace Propulsion** at **TU Darmstadt** in Germany tested a small-scale RDE powered by gaseous hydrogen and oxygen in April, to identify the operating characteristics of RDEs with comparable total mass flows to satellite thrusters. The **German Aerospace Center's, or DLR's, Institute of Space Propulsion** conducted initial tests in May on an RDE with oxygen/hydrogen and oxygen/methane to determine the operating characteristics of RDEs for rocket propulsion, including gas generator applications.

At Poland's **Institute of Aviation**, researchers continued to mature their **liquid kerosene-air, hollow ramjet RDE** with prolonged operation in a water-cooled configuration. In September, they conducted the first experiments with a calorimetric 3D-printed hydrogen-air RDE to gather data on heat loads and temperatures.

The **Romanian Research and Development Institute for Gas Turbines** in July partnered with the **von Karman Institute for Fluid Dynamics** in Brussels and the **Polytechnic University of Madrid** to study pulsed and rotating detonation combustion.

In June, researchers at the **University of Central Florida** demonstrated Jet-A aerosolized 5-micrometer monodispersed liquid fuel cloud detonations, showing the dynamics and details of the droplet burning behavior. In March, **NASA's Marshall Space Flight Center** in Alabama conducted ground tests of a 10,000-pound-force dual regenerative fully additively manufactured RDE, powered by liquid methane and liquid oxygen. The team achieved the highest average pressure, operating the RDE at 750 pounds per square inch absolute, and is now preparing for a ground demonstration of the world's first turbomachinery integrated RDE lander for the moon or Mars.

The **U.S. Naval Postgraduate School** in California continued to analyze the design, operability and performance impact of fuel injection strategies for RDE designs. In May, researchers at **Argonne National Laboratory** in Illinois developed a one-of-its-kind high-order discontinuous Galerkin spectral element method framework within their Nek5000 flow solver to simulate detonative combustion.

In March, researchers at **Purdue University** of Indiana and **Spectral Energies** of Ohio demonstrated megahertz-rate heat-flux measurements in a hydrogen-air RDE via an **atomic layer thermopile**. They compared their results to numerical predictions of local transient heat fluxes previously conducted at **North Carolina State University**. In February, with **NASA's Glenn Research Center** in Ohio, the Purdue and Spectral team investigated liquid injection in RDEs and captured the first million-frames-per-second **volumetric fluorescence images** of detonation-spray interactions. In May, they demonstrated phase **Doppler interferometry** for the first time within the RDE. The observed drop size distributions suggested substantial breakup and atomization of liquid jets.

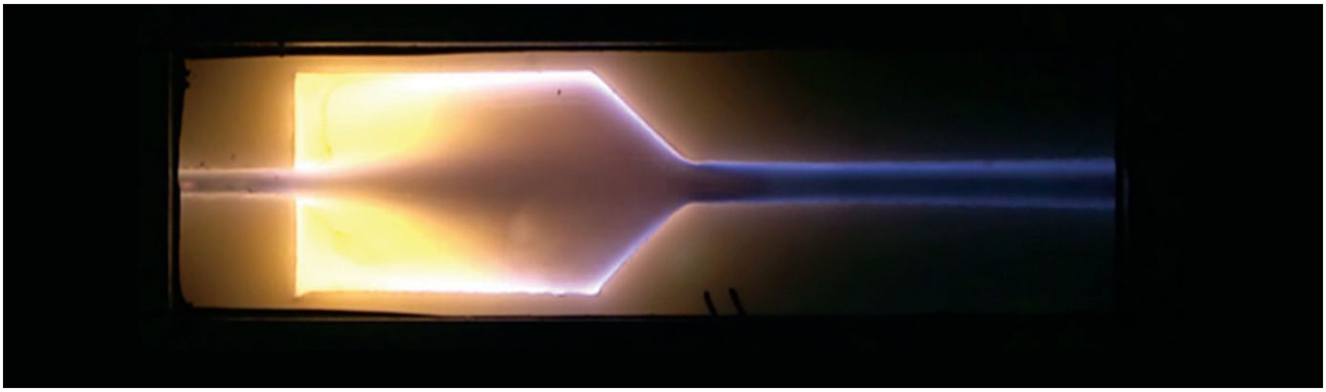
At the **University of Alabama** in Huntsville, a small-scale RDE was tested in June with multiple fuel-oxidizer combinations to prove its operability, characterize performance and inform the design of efficient, compact chemical satellite thrusters. In November, researchers from **Nagoya University, Muroran Institute of Technology, Keio University and the Japan Aerospace Exploration Agency** launched a pressurized liquid ethanol-nitrous oxide RDRE aboard a sounding rocket. It produced 438 newtons of thrust and a specific impulse of 244 seconds ★

Contributors: *Venkat Athmanathan, John W. Bennewitz and Jason Burr*

Advances reported in detonation-based systems and solid-fuel scramjets

BY WARUNA KULATILAKA AND SHYAM MENON

The **Propellants and Combustion Technical Committee** works to advance the knowledge and effective use of propellants and combustion systems for military, civil and commercial aerospace systems.



▲ Virginia Tech researchers fired a model solid-fuel scramjet with an optically accessible combustor by replacing two side walls with quartz windows.

Virginia Tech/Gregory Young

Among the year's advancements, milestones related to cutting-edge combustion concepts such as **rotating detonation engines, RDEs,** and **solid-fuel scramjets** gained attention due to potential performance enhancements and the ability to simplify engine components while increasing the power-to-weight ratio.

The coveted pressure gain combustion in RDEs continued to elude researchers. In January, researchers from the **Royal Military College, University of Ottawa** and **National Research Council of Canada's Aerospace Research Centre** reported in an article in the **Journal of Propulsion and Power, JPP**, on a quasi-two-dimensional approach to simulate the injectors of RDEs. Their streamline and particle-tracking analyses confirmed that over-expansion shock waves in the injectors were responsible for significant stagnation pressure losses that overcame pressure gains from detonation. The study suggests that careful injector sizing and design may be key to achieving net pressure gain combustion in RDEs.

RDEs also offer a revolutionary technology for **land-based power generation**, offering potential improvements in efficiency and emissions reduction. In an April JPP article, researchers at the **National Energy Technology Laboratory** and **West Virginia University** described their multiyear survey of machine learning approaches to improve capabilities for real-time monitoring of RDEs, a major step toward active control of these engines in laboratory and industrial settings. By evaluating various **convolutional neural networks** for image classification, object detection and time series classification, they identified methods capable of **real-time detonation wave analysis**.

In **rotating detonation rocket engines**, injecting rocket propellants in both gaseous and liquid phases offers a wide array of choices. Liquid/liquid injection systems provide the highest theoretical advantage but operate at the most arduous conditions. In August, **Purdue University** researchers described their investigation of cryogenic systems with direct injection of liquid oxygen with kerosene or cryogenic methane fuels. Their work on these propellant combinations, published in JPP, resulted in successful detonation of both fuels. Additional work focused on storable liquids — hydrogen peroxide oxidizer with hydrocarbon fuels.

In July, **University of Central Florida** researchers concluded their investigation of liquid fuels for detonation applications. In a paper published in the **Proceedings of the Combustion Institute**, they described the droplet burning behavior at varying amounts of nitrogen dilution at stoichiometric and rich equivalence ratios, illustrating how these parameters affect the detonation characteristics of liquid fuels.

With increasing attention to hypersonic flight and related propulsion systems, a team of researchers at **Virginia Tech** investigated a simpler method for achieving this goal with **solid-fuel scramjets**. In March, they conducted experimental and computational work, achieving flameholding and sustained combustion at considerably lower total temperatures than those previously reported. Additionally, they developed the first known **fully optically accessible solid-fuel scramjet**. Their work, described in a journal article published in JPP, led to a greater understanding of the flowfield within the combustor, improving flameholding and flammability limits. ★

Contributors: *Kareem Ahmed, Stephen Heister, Kristyn Johnson-May, S. She-Ming Lau-Chapdelaine, Andrew Nix and Gregory Young*

Solid rocket motors support growing number of rocket launches and missile tests

BY CLYDE E. CARR JR. AND JOSEPH MAJDALANI

The **Solid Rockets Technical Committee** studies techniques applied to the design, testing and modeling of rocket motors based on solid propellant grains.

▲ A United Launch Alliance Atlas V lifts off from launch pad 41 at Cape Canaveral Space Force Station in Florida. This was the 53rd flight of an Atlas V and the design's final launch for the U.S. Space Force.

U.S. Space Force/Joshua Conti

The year's achievements showcased the essential role of **solid rocket motors, SRMs**, in civil spaceflight, tactical and strategic missile programs, and their growing importance in space exploration.

In January, **Northrop Grumman** completed a **static fire test** of a motor like the one that will propel each second stage of the **Sentinel intercontinental ballistic missiles**. The test, performed in a vacuum chamber at the **U.S. Air Force's Arnold Engineering Development Complex** in Tennessee, was followed by shroud fly-off and missile modal tests at the company's Utah plant in February. The ground-launched Sentinels are to replace the Minuteman IIIs and operate through 2075.

In tactical missile developments, **Lockheed Martin** achieved several milestones. In March, the company conducted flight tests of two **Extended Range Guided Multiple Launch Rocket Systems**, with a follow-up test in September at **White Sands Missile Range** in New Mexico, moving the design closer to operational deployment by the Army. In April, Lockheed Martin received a $483 million contract to produce additional **Joint Air-to-Ground Missiles and Hellfire II missiles**.

In the missile defense sector, two U.S. Navy destroyers in April and October fired a dozen solid-fueled **Standard Missile-3 interceptors** out of the Mediterranean Sea to intercept **Iranian ballistic missiles**, the first combat use of the interceptors. In a March test, an **upgraded SM-6 missile** launched from an **Aegis** ship intercepted a Northrop Grumman two-stage solid-fueled **Medium Range Ballistic Missile target** in a ballistic missile detection, tracking and interception exercise.

In May, **Lockheed Martin** launched a **PAC-3 Missile Segment Enhancement interceptor**, impacting a cruise missile for the first time. The test at White Sands expanded the use of the PAC-3 missile system to **Aegis** ships.

In the realm of launch vehicles, **United Launch Alliance** in January launched its inaugural **Vulcan Centaur** rocket, the planned successor of its Atlas Vs. Vulcan lofted the Peregrine lunar lander to orbit, supplemented by two **GEM-63XL strap-on solid boosters**, the longest monolithic SRBs ever manufactured. In October, ULA launched the second Vulcan, setting the design up to launch payloads for the U.S. Space Force, pending a review from the service. In June, an **Atlas V** launched two NASA astronauts in a **Boeing Starliner capsule** toward the International Space Station, the first time an Atlas V carried humans. In July, an Atlas V sent a Space Force satellite to orbit, ULA's final national security launch with the design.

Europe also saw the debut of a new rocket. In July, the first **Ariane 6** sent several satellites to orbit. This marked a new chapter for European space exploration, as multiple Ariane 6 configurations are available for different mission requirements. September marked the end of another chapter: The last **Vega** rocket was launched, lofting the **Sentinel-2C** satellite.

Throughout the year, growth in the SRM industry was driven by established companies and new players. In January, **Aerojet Rocketdyne** (now part of L3 Harris) partnered with the **Naval Surface Warfare Center Indian Head Division** to increase SRM production. **Raytheon** announced partnerships with **Avio** of Italy and **Nammo** of Norway to expand U.S. military SRM manufacturing. In August, California-based **Anduril** announced a $75 million funding allocation toward a new state-of-the-art SRM production facility. Denver-based **Ursa Major** in September received a Pentagon contract for 3D printing SRM components. In June, **X-Bow** of New Mexico received contracts to develop **Mk72 and Mk104 boosters** for the **Navy's Standard Missiles**. In August, the company completed a preliminary design review for the **Large Solid Rocket Motor** being developed for the Department of Defense.

The future of solid propulsion systems looks more promising than ever, paving the way for keystone advancements and expanded production capability on the near horizon. ★

Contributors: *Russ Ellis, Timothy Kibbey, Agostino Neri and Wesly Ryan*

Adopting ammonia fuel for marine vessels and pushing toward wider use of liquid hydrogen fuel

BY TOSHIRO FUJIMORI, KEIICHI OKAI AND S.A. SHERIF

The **Terrestrial Energy Systems Technical Committee** works to advance the application of engineering sciences and systems engineering to the production, storage, distribution and conservation of energy for terrestrial uses.

▲ The tugboat Sakigake was remodeled with ammonia-fueled engines and delivered this year to the Port of Yokohama in Japan, making it the first ammonia-fueled vessel for commercial use, its developers said.

NYK Line

Transitioning shipping to **ammonia fuel** is a high priority of the Japanese government's "green growth strategy." In August, the vessel **Sakigake** was delivered to the **Port of Yokohama**, making it the world's **first ammonia-fueled tugboat for commercial use**, its developers said. Formerly powered by liquefied natural gas, Sakigake was remodeled by **NYK Line and IHI Power Systems** under Japan's New Energy and Industrial Technology Development Organization. In offshore operation, each engine achieved a maximum 95% mixing ratio of fuel ammonia, and ammonia and nitrous oxide concentrations were sufficiently removed by an exhaust gas after-treatment system to ensure 90% greenhouse gas reductions. Ammonia fuel emits no carbon dioxide, leading to significant emissions reductions in power generation and transportation applications. For example, the **International Maritime Organization** adopted the 2023 IMO Strategy on Reduction of GHG Emissions from Ships, which aims to reduce carbon emissions in international shipping by 40% by 2030 relative to 2008 levels and reach zero emissions by or around 2050.

On the **hydrogen fuel** front, the **U.S. Department of Energy** in April announced the winners of phase two of its **Hydrogen Shot Incubator Prize Competition**, which funds "disruptive technologies that reduce the cost of producing clean hydrogen." **Electro-Active Technologies** of Tennessee, **Green Fortress Engineering** of Indianapolis, **NX Fuels** of Michigan and **PAX Scientific** of California are each to receive $400,000 in lab vouchers and funds. This initiative calls for reducing the cost of **clean hydrogen** by 80% by 2030, which equates to $1 per kilogram. In May, **DOE's Hydrogen and Fuel Cell Technologies Office** released its "Multi-Year Program Plan" for achieving that and related goals, including a target of $2/kilogram by 2026.

Once produced, hydrogen needs to be stored for use in different applications. In the transportation sector, for example, **liquid hydrogen, or LH2,** is convenient because it has a larger storage density relative to gaseous storage. Onboard storage in vehicles enables burning hydrogen in internal combustion engines or using it in a fuel cell. Liquefying hydrogen has historically consumed a significant part of the available combustion energy. For example, the minimum energy required for classical theoretical liquefaction cycles is greater than 10 kilowatt-hours per kilogram of LH2. While some expander cycles can in theory deliver liquefied hydrogen below 6 kWh/kg, some large plants in operation today still consume 13-14kWh/kg. The DOE has set a target of 6 kWh/kg.

Liquid storage is also typically associated with relatively high **boil-off losses**. To address that challenge, upgraded refrigeration/pre-cooling cycles such as the high-pressure Claude cycle and some mixed refrigerant cycles are used. Scaling up liquefaction plants to above 100 tons/day is key to higher efficiencies. This year's advances in raising the liquefaction efficiency include the development of **oil-free scroll compressors** by "Beyond Scroll," with compressors capable of compressing hydrogen from atmospheric pressure without contamination, thus reducing system components and maintenance costs. Beyond Scroll's compact compressors operate at high speeds with only 120 kilowatt-electric of input power.

Other advances include the development of **metal hydride hydrogen compressors, MHCs**, for transportation. Greek startup **CYRUS** did this with **thermal-powered MHCs** absorbing hydrogen at low pressure and temperature with an external heat source. In the area of liquid storage, optimization of vessel shape and employing vacuum-jacketed insulation are being used. Research is currently addressing the whole LH2 production and supply chain, including using catalysts to speed-up ortho-para conversion during liquefaction, larger refrigeration units during transportation, baffles in trucks to reduce sloshing and finding innovative ways to reduce flashing during unloading of LH2. DOE's increased emphasis on transitioning to a **hydrogen economy** prompted numerous researchers to work on all aspects of this transition. A review of these developments appeared in the Feb. 29 issue of the **International Journal of Hydrogen Energy**. ★

A Mars analog mission concludes, NASA's spacesuit challenges continue

BY JONATHAN G. METTS

The **Life Sciences and Systems Technical Committee** advances technologies required to keep people healthy and safe as they explore space.

▲ This four-person, volunteer crew in July concluded an analog mission that simulated a yearlong stay on the surface of Mars. From their Mars Dune Alpha habitat at NASA's Johnson Space Center in Texas, the crew completed spacewalks and other activites meant to gauge their physical and mental health in an isolated environment.
NASA

In July, the four-person crew of **NASA's Crew Health and Performance Exploration Analog, CHAPEA** emerged from their 160-square-meter habitat at **NASA's Johnson Space Center** in Texas. During their 378 days in self-sufficient isolation meant to simulate a year on the surface of Mars, the all-volunteer crew grew their own food and suited up for simulated surface operations. Their **Mars Dune Alpha** habitat, a 3D-printed facility, was constructed by Austin-based **ICON Technology**.

Such long-duration analog missions are the basis of research for fields as diverse as space architecture, space medicine and space psychology, because they allow researchers to study the performance of small, multisex teams living for months or years in isolated, extreme environments. To study the effects of communication delays between Earth and Mars, CHAPEA mission controllers restricted external communications by enforcing a time delay of up to 22 minutes. At the emergence ceremony, NASA astronaut and Deputy Director of Flight Operations Kjell Lindgren said that the CHAPEA crew "committed a year of their lives in service to NASA, the country, and humanity's exploration of space."

On the **International Space Station**, spacesuit issues continued to challenge **EVAs, extravehicular operations**. A June spacewalk was aborted when **NASA astronaut Tracy Dyson** reported a water leak in the servicing and cooling umbilical of her **Collins Aerospace**-built suit as she was preparing to exit the airlock. The leak sprayed ice crystals throughout the airlock in a "snowstorm," as described by fellow astronaut Suni Williams, who observed through the inner hatch's window. Similar leaks occurred in 2013, 2015, 2022 and 2023, and multiple cases resulted in water collecting inside the astronaut's helmet. European Space Agency astronaut Luca Parmitano experienced this water collection during two spacewalks.

An additional challenge arose on the ground. NASA in June announced that it and **Collins Aerospace** agreed to end a task order under which Collins was to develop new suits for the remaining years of ISS operations. The order had also required Collins to deliver a suit for an on-orbit flight demonstration in 2026, but the company "recognized that its development schedule would not support the space station's schedule and NASA's mission objectives," NASA said in a news release. This leaves **Axiom Space** of Texas as the sole contractor under **NASA's Exploration Extravehicular Activity Services** program.

Axiom reported progress with its lunar surface suit, including an unoccupied water submersion test in April at the **Neutral Buoyancy Laboratory** in Houston. Also, in early June, an Axiom Space employee and a NASA astronaut donned spacesuits and entered a pressurized mockup of a **SpaceX Starship lander.** Plans call for a Starship to ferry astronauts from lunar orbit to the lunar south pole in the **Artemis III** landing. Axiom also has a task order from NASA to create a variant of its spacesuit for spacewalks on ISS and future commercial space stations.

Meanwhile, in September, billionaire **Jared Isaacman** and SpaceX engineer **Sarah Gillis** donned SpaceX's new extravehicular suits during their **Polaris Dawn** flight. They took turns partially exiting the Crew Dragon capsule for **"stand-up EVAs"** that resembled some of those performed during the early Apollo flights. And in October, China unveiled a moonwalking version of its Feitan suit, which taikonauts will wear during the nation's first crewed moon landing, scheduled to occur before 2030. ★

Embarking on a new decade of space exploration research

BY ÁLVARO ROMERO-CALVO

The **Microgravity and Space Processes Technical Committee** encourages the advancement and public awareness of low-gravity studies in physics, materials, biological sciences and related fields.

Many of this year's achievements and activities were dictated by the priorities laid out in the National Academies' latest **decadal survey on biological and physical space sciences**, published in September 2023. Guided by those recommendations, the low-gravity space processes community continued working toward a future where humans thrive in space.

In August, **Rob Ferl of the University of Florida** became the first NASA-funded academic researcher to personally conduct his own experiments in microgravity. Sponsored by the **NASA Flight Opportunities Program**, Ferl was among the six-person crew of **Blue Origin's NS-26 mission**. Upon reaching an altitude of 105 kilometers in the **New Shepard** capsule, Ferl opened test tubes with plant samples attached to his suit to analyze how biology is impacted by changes in gravity. In June, under the same NASA program, a next-generation **microgravity 3D printer** developed by researchers at the **University of California, Berkeley** was flown onboard **Virgin Galactic's VSS Unity** spaceplane. Also during this flight, Galactic 07, a rotational slosh experiment from the **University of Purdue** was conducted to analyze the rate of damping of propellant motion after a rotational spacecraft maneuver. NASA also continued flying experiments aboard parabolic aircraft, conducting 57 tests aboard Florida-based **Zero Gravity Corp.'s Boeing 727** between January and August.

In June, some 100 institutions from 25-plus countries worked together to coordinate the publication of the **Space Omics and Medical Atlas**. This package of manuscripts, data, protocols and code is the largest-ever compendium of data for aerospace medicine and aerospace biology. It represents a tenfold increase in publicly available human space omics data, a fourfold increase in the number of single cells processed from spaceflight, the launch of the first aerospace medicine biobank, the first-ever **direct RNA sequencing data** from astronauts, the largest number of processed biological samples from a mission and the first-ever **spatially resolved human transcriptome data**.

▼ During a flight aboard a Blue Origin New Shepard in June, Rob Ferl, a professor at University of Florida, opened test tubes with plant samples to see how exposure to microgravity would affect them. Ferl spent four minutes in weightlessness above the Kármán line.

Blue Origin

Between January and June, the **ISS National Laboratory** sponsored and delivered to the **International Space Station** some 100 payloads on fundamental science, technology development, in-space manufacturing and STEM education investigations. These spanned NASA-funded missions, as well as private astronaut flights through **Axiom Space** of Texas.

August marked the 10-year anniversary of the **European Space Agency's electromagnetic levitator**, a facility that hosted three U.S. investigations this year — from **Tufts University** in Massachusetts, **Washington University** in St. Louis and **Worcester Polytechnic Institute** in Massachusetts — all of them sponsored by **NASA's Division of Biological and Physical Sciences**. One of the Washington University researchers studied the structure and physics of metallic liquids and glasses to develop new theories on glass formation.

In July, the **ISS National Lab** and **NASA's Division of Biological and Physical Sciences** announced the five recipients of the inaugural **Igniting Innovation solicitation** to conduct cancer research on the ISS. The winners will receive a combined $7 million to fund multiple experiments on the ISS.

With the ISS scheduled to be deorbited in early 2031, NASA continued to support the development of **commercial low-Earth orbit destinations**. In January, NASA added $99.5 million in funding to its existing Space Act Agreements with **Blue Origin** and **Voyager Space**, who are each developing private space stations. In October, California-based **Vast** revealed the final design of **Haven-1**, the first of its planned orbital research and manufacturing space stations, with its partners Redwire and Yuri. The laboratory is scheduled to launch with a privately funded crew of four no earlier than the second half of 2025. ★

Contributors: *Kenneth Lui and Antoni Perez-Poch*

Missile defense industry takes steps to meet modern demands

BY DAVID FOX

The **Missile Systems Technical Committee** focuses on technologies associated with the design, development, operations and utilization of strategic and tactical missile systems.

▲ The U.S. Missile Defense Agency in April selected Lockheed Martin to build the Next Generation Interceptors that would be fired against long-range ballistic missiles.

Lockheed Martin

As of October, the U.S. has provided approximately $64.1 billion worth of weapons and equipment to **Ukraine** since Russia invaded in February 2022. Its expenditure has driven a need to replenish the U.S. inventory of missile systems, so in August, the **U.S. Army** awarded a $1.3 billion contract to **Lockheed Martin** and **Raytheon** to produce additional **Javelin missiles**.

In addition, development of **hypersonic and counter-hypersonic weapons** continued, alongside more low-cost technologies for **counter drone** missions. This demand for increased, expedited development and production, often with reduced budget, has begun reshaping the domestic missile defense industrial base. In July, Raytheon's parent organization, **RTX**, signed a contract with **Avio** of Italy to develop **solid rocket motors,** or SRMs, to bolster the U.S. defense industrial base and that of its allies. In August, **Lockheed Martin** and **General Dynamics** announced their strategic teaming agreement for the production of SRMs to bring increased resiliency to the domestic supply chain.

These revised acquisition approaches may allow Raytheon and Lockheed Martin to stay competitive with the other primary SRM suppliers: **Northrop Grumman**, which established in-house motor production via its acquisition of Orbital ATK in 2018, and **L3Harris**, which last year completed its acquisition of **Aerojet Rocketdyne**.

Outside of these large contractors, the **U.S. Navy** in April and June awarded contracts to startups **Xbow, Ursa Major and Anduril Industries** to develop solid rocket motors for the **Standard Missile franchise**, indicating these emergent suppliers can compete with incumbent defense industry contractors. Ursa Major and Anduril have only just entered the SRM industry, with Ursa Major announcing plans to develop and produce SRMs last year, and Anduril adding SRM technology to its portfolio last year with its purchase of **Adranos**, a Purdue University-affiliated startup.

Beyond the SRM market, California startup **Castelion** in March tested a prototype of its **hypersonic missile**. Also that month, **Stratolaunch** of California conducted the first powered flight of one of its reusable **Talon-A** vehicles, demonstrating the expansion of **U.S. hypersonic testing services**. In August, **Lockheed Martin** selected **Voyager Space** to provide the propulsion for the **Next Generation Interceptor** it is building for the **Missile Defense Agency**. Voyager in 2021 acquired **Valley Tech Systems**, a California startup developing solid propulsion for hypersonic vehicles. Lockheed Martin's selection demonstrated that these atypical companies can grow beyond initial research and development and into substantive product development.

While the lasting impacts of emerging small companies alongside the conventional prime contractors is still to be determined, it appears that the U.S. industrial base is attempting to meet the challenge of increased demand. Such a diverse supply base could provide myriad defense solutions to answer future challenges to the U.S. and its allies. ★

Widespread reusability starts to become a reality

BY ZACHARY FRIEDMAN, AMRUTUR ANILKUMAR AND BOB SEIBOLD

The **Reusable Launch Vehicles Technical Committee** promotes the development and implementation of operationally responsive and economically viable commercial, military and civil reusable launch vehicles and systems for space access and global reach.

This was a year of advancements for reusable launch vehicles. While most eyes were on **SpaceX**, which achieved its first **Super Heavy booster catch** in October, other launch providers steadily hit key milestones on the path to both partial and full rocket reusability. In contrast to the focus on small, inexpensive, expendable rockets just a few years ago, providers are now aiming for larger reusable rockets to ensure cost competitiveness.

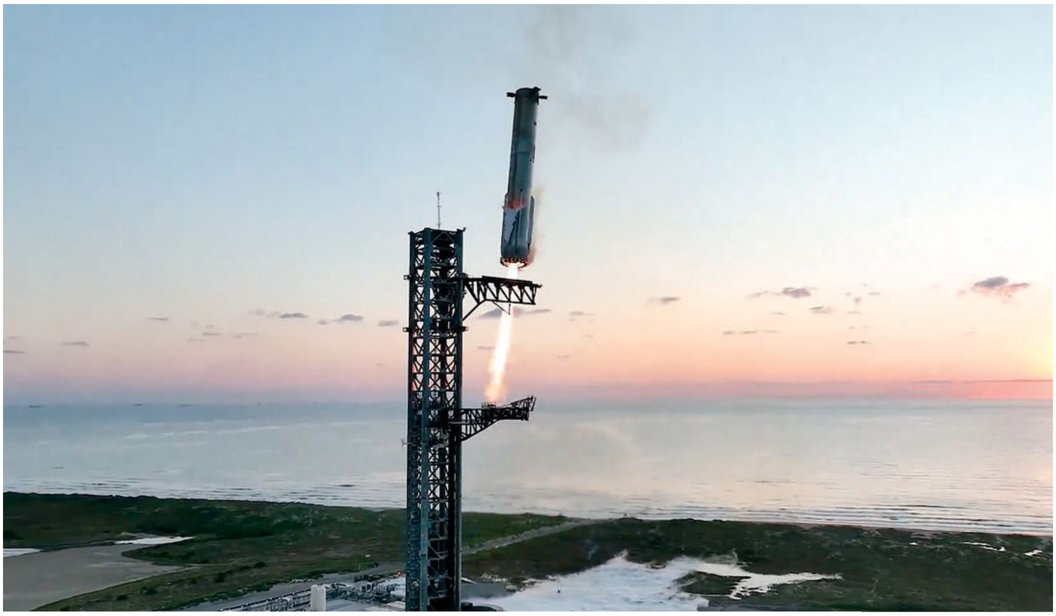
SpaceX continued to lead the pack for reusable launch. Four **Starship-Super Heavy** rockets were launched this year, following the two launches in 2023. Meanwhile, SpaceX's workhorse **Falcon 9** rockets set another record for first-stage reuse. The B1062 booster completed its 23rd flight in August, though it fell over and broke apart shortly after landing on the droneship. Looking ahead, planned milestones in 2025 include the first tower catch of a Starship upper stage, plus a transition from test launches into operational capability.

Rocket Lab, the small-lift launch provider with the second-highest launch cadence behind SpaceX, marked progress in developing its reusable **Neutron** medium-lift vehicle. In May, the company announced that Neutron's debut would be delayed one year to 2025, but developments continued to take place. The first static fire tests with an **Archimedes** engine were completed in August, and the engine was to enter qualification testing and full volume production. Rocket Lab also announced in August that design work for Neutron is complete and that all components have been moved to production or qualification.

Stoke Space, a startup based in Kent, Washington, achieved several milestones in its quest to challenge SpaceX in developing the first fully and rapidly reusable rocket. Stoke completed initial test fires of the first-stage engine in June, just 18 months after design began. While targeting an inaugural launch of its **Nova** rocket in 2025, Stoke is awaiting the completion of an environmental assessment before it can begin to retrofit its Cape Canaveral launch site. In July, Stoke was awarded an **Orbital Services Program-4** contract from the **U.S. Space Force**, making the company eligible to compete for up to $986 million in national security launch contracts through 2028.

Also inching closer to flight was **Blue Origin's New Glenn**, a heavy-lift design with a reusable first stage. First announced in 2015, New Glenn passed a series of milestones this year, including being raised vertically at its launch pad in February. For the inaugural launch, New Glenn is to send a **Blue Ring** orbital transfer vehicle to orbit. Blue Origin was also awarded several government launch contracts, including securing a late spot in June to compete with incumbents **SpaceX** and **United Launch Alliance** for up to $5.6 billion in launches under the **National Security Space Launch Phase 3** program. In July, Blue Origin was also awarded a spot on the OSP-4 contract alongside Stoke.

Reusable rocket development continues to increase outside the U.S. as well, most notably in China and India. Chinese rocket startup **Deep Blue Aerospace** announced four funding rounds between May and August, and conducted a partially successful first-stage flight in September. In total, nine Chinese firms plan to debut rockets in the coming years, with at least half developing partially reusable rockets. In June, India completed the third and final glide test of its **Pushpak** reusable spaceplane. With testing complete, the **Indian Space Research Organisation** now aims for an orbital launch and return. ★



▼ SpaceX in October for the first time caught a Super Heavy booster at the launch tower in Boca Chica, Texas. The booster sent a Starship upper stage to orbit, then fired its engines to return to the launch tower, coming to a stop between the tower's "chopsticks," or mechanical arms.

SpaceX

Number of small satellite launches continues to grow, with no end in sight

BY MICHAEL SWARTWOUT AND CARRIE O'QUINN

The **Small Satellite Technical Committee** works to advance the science and engineering of satellites, launch vehicles and ground systems to enable the development of small and highly capable spacecraft.

▲ This picture of a discarded rocket upper stage was taken by Astroscale's ADRAS-J spacecraft in July. The demonstration mission achieved several firsts, including the first time a spacecraft has approached and operated in close proximity to an uncontrolled object in orbit.

Astroscale

Small satellites continued to serve as platforms for technology demonstrations and operational missions, serving national, commercial and educational objectives. In January, the **Space Industry Responsive Intelligent Thermal** satellite began science operations with its **Italian Space Agency** gamma ray instrument. The 6-unit bus built by **Inovor Technologies** of Australia is the first to use a **Stirling cycle cryocooler** on a platform of this size.

In March, the **AEROS MH-1** nanosatellite was launched into low-Earth orbit, the second-ever Portuguese spacecraft. **Thales Edisoft Portugal** led the mission, which involved commercial, research and academic groups in Portugal and from **MIT**. AEROS MH-1 is the first of a planned constellation for ocean monitoring via space-based and ocean-based sensors. Launched on the same rocket was the **Rapid Revisit Optical Cloud Imager** satellite built by **Orion Space Solutions** of Colorado to provide high-resolution weather information to the **U.S. Space Force**.

In August, **NASA's Advanced Composite Solar Sail System** deployed its 80-square-meter solar sail, the second-largest sail to operate on orbit. This demonstrator is testing **composite boom technologies** developed by **NASA's Langley Research Center** in Virginia that could made much larger sailcraft possible. ACS3, led by **NASA's Ames Research Center** in California, uses a bus from **NanoAvionics**, headquartered in Lithuania.

Several technology demonstrations in the field of **rendezvous and proximity operations** occurred, among them **NanoFF**. These twin 2-unit cubesats, built by the **Technical University of Berlin**, in September demonstrated **proximity navigation**. In May, **Starfish Space's Otter Pup** rendezvoused with another spacecraft and captured an image of it. In July, **Astroscale** announced that its **ADRAS-J** spacecraft had performed an approach, controlled fly-around and imaging of the discarded rocket upper stage.

Each of these small spacecraft reached orbit on rockets carrying a dozen other payloads — or dozens. Because operators can fit so many on one launch vehicle, the number of small satellites deployed this year neared all-time highs. As of mid-November, 475 small satellites were carried on 55 launches — with individual flights carrying up to 120 spacecraft. A notable exception to this multi-spacecraft trend was the **Polar Radiant Energy in the Far-InfraRed Experiment** mission, led by the **University of Wisconsin**. These twin 6-U spacecraft, built by **NASA's Jet Propulsion Laboratory,** flew solo on **Rocket Lab Electron** vehicles in May and June. The mission aims to fill critical gaps in measurements of the far-infrared spectrum in the Arctic to create more detailed climate models.

There was a new **U.S. Federal Communications Commission** rule that will directly impact small satellites. As of Sept. 29, all FCC-licensed spacecraft must be disposed of within five years of the end of their mission, instead of 25 years. This reduction will likely decrease the number and type of small spacecraft operating in higher altitudes. Today, only a small proportion of small satellites have **active propulsion** or **deorbit systems**, so either fewer spacecraft will operate at those altitudes or a higher proportion must incorporate those technologies. In February, FCC proposed a new framework for licensing **in-space servicing, assembly, and manufacturing, ISAM,** activities. If adopted, these rules would accelerate the licensing process, potentially increasing the use of small satellites for ISAM demonstrations.

Finally, as demonstrated by AEROS MH-1 and many other missions, small satellites continued to be an effective means for organizations and nations to access space: Upwards of 20 universities and private companies put their first-ever spacecraft into orbit this year. In January, Ireland became the 80th nation to operate its own spacecraft with the launch of **EIRSAT-1**. ★

Contributors: *Scott Palo and Paula do Vale Pereira*

Commerce spreads in low-Earth orbit as government agencies set their sights higher

BY THEODORE W. HALL

The **Space Architecture Technical Committee** focuses on the architectural design of the environments where humans will live and work in space, including facilities, habitats and vehicles.

In January, **NASA** announced modifications to Space Act agreements with **Blue Origin** of Washington and **Voyager Space** of Colorado for low-Earth orbit space stations. Blue Origin, working with **Sierra Space** of Colorado and others, received an increase of $42 million for its **Orbital Reef** station. Voyager Space, working with **Airbus**, received an additional $57.5 million for development of its **Starlab** station.

In March, **NASA** confirmed that **Orbital Reef's life support system** had passed four key development tests: trace contaminant control, water contaminant oxidation, urine water recovery and water tank validation.

Sierra Space and **ILC Dover** of Delaware conducted pressure tests with models of Serra's inflatable LIFE modules that are planned to comprise much of the Orbital Reef complex. In January, they announced the results of a December 2023 full-scale test at **NASA's Marshall Space Flight Center** in Alabama. The test registered 531 kilopascals (77 pounds per square inch), which is five times the maximum intended operating pressure, before the module's explosive burst. In June, they repeated the feat, reaching 510 kilopascals (74 pounds per square inch). The LIFE module has a volume of 285 cubic meters.

Meanwhile, in April, **Mitsubishi Corp.** of Tokyo joined the Starlab partnership as an equity owner and prospective station occupant for industrial research.

Vast Space of California also pressed forward in developing **Haven-1,** the first of its planned commercial space stations. In April, the company announced an agreement with **SpaceX** to equip Haven-1 with a **Starlink laser terminal** to provide gigabit-per-second communication for the crew, payload racks, external cameras and other instruments. In June, Vast announced a memorandum of understanding with the **European Space Agency** to study future European access to Vast's planned stations.

At the other end of cradle-to-grave real-estate management, **NASA** in June selected **SpaceX** to develop a **deorbit vehicle** to guide the **International Space Station** on a controlled reentry toward a safe oceanic interment at its end of service, currently scheduled for 2030. The agency considered but ultimately ruled out proposals for preserving ISS by boosting it to a higher orbit or partially disassembling it.

▼ This mockup of the International Habitation Module that would be part of NASA's Lunar Gateway space station was created by a consortium of LIQUIFER Space Systems, Haux LIfe Support and Spartan Space. NASA plans to station Gateway in a high near-rectilinear orbit around the moon, as a habitat and research facility for astronauts visiting the lunar surface under the Artemis program.

Spartan Space

In the realm of **suborbital near-space tourism**, **Space Perspective** of Florida in August completed construction of **MS Voyager**, a vessel that will serve as a marine spaceport for launching its **Spaceship Neptune** stratospheric balloon. The company is coordinating with the **U.S. Coast Guard** as well as **FAA** for sea-based launches and splashdowns.

Leaving Earth orbit increasingly in the hands of the commercial sector, space agencies increased their focus on the moon and beyond. In January, **NASA** announced that the **United Arab Emirates** would provide the **Crew and Science Airlock module** for the planned **Lunar Gateway** station, and that a UAE astronaut would fly to Gateway on a future Artemis moon mission. This demonstrated increasing global participation in space architecture, design and construction.

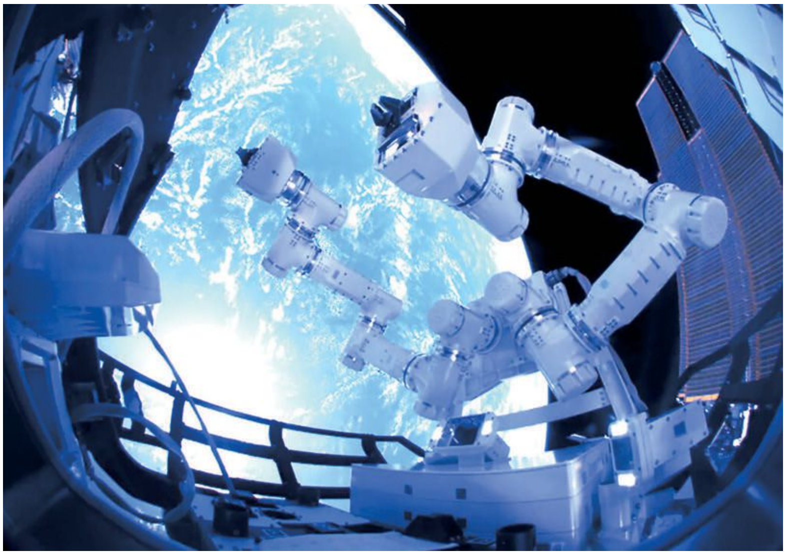
In March, an industrial consortium managed by **LIQUIFER Space Systems** of Germany delivered an integrated mockup of **Gateway's International Habitation module** to the module's prime contractor, **Thales Alenia Space** of Italy. **Haux Life Support** of Germany provided the primary structure, and **Spartan Space** of France provided dimensionally accurate stand-ins for interior equipment to support simulations of human activities in the habitable volume.

In July, the first four-person volunteer crew emerged from a **378-day simulated Mars surface mission**. The analog mission in the **Crew Health and Performance Exploration Analog habitat** at **NASA's Johnson Space Center** in Texas included habitat maintenance, health maintenance and crop growth, with intentional stressors of resource limitations, isolation, confinement and time-delayed communication with the outside world. ★

Expanding the final frontier with robots

BY CHUCK SULLIVAN, SAMANTHA CHAPIN AND OU MA

The **Space Automation and Robotics Technical Committee** works to advance the development of automation and robotics technologies and their applications to space programs.



▲ California startup GITAI demonstrated in-space servicing and assembly tasks with its S2 robotic arm, at center, outside the International Space Station in March.

GITAI

It was a rollercoaster of a year for robotics, with major investments and achievements, along with some unexpected events.

With a plethora of lunar landers in development, rovers for exploration are a major focus. At **NASA's Jet Propulsion Laboratory**, the **Cooperative Autonomous Distributed Robotic Exploration** project in January completed construction and testing of its rovers. Also that month, **Lunar Outpost** of Colorado announced plans to land a third rover on the lunar surface, aboard an **Intuitive Machines lander**. In July, NASA announced the cancellation of **VIPER, the Volatiles Inspecting Polar Exploration Rover** mission, but as of November was assessing proposals from industry to take over VIPER and its lunar ice-scouting mission.

There were also developments in robotics for **human exploration**. In May, **MIT** presented a paper at the **International Conference on Robotics and Automation** on its **SuperLimbs** concept for wearable robotic limbs. And in April, NASA selected three companies to continue refining concepts for a highly autonomous **Lunar Terrain Vehicle** for crewed lunar landings under the **Artemis** program.

In-space servicing, assembly and manufacturing, or ISAM, efforts continued to grow. Some 300 people attended the **Consortium for Space Mobility and ISAM Capabilities Convergence Conference** in May. There, COSMIC announced its first student competition, the COSMIC Capstone Challenge, which will run through April 2025. In March, **GITAI** of California robotically constructed a 5-meter-tall communications tower in a ground demonstration that replicated the lunar environment. A few weeks later, GITAI completed an assembly demonstration with its **dual robotic arm** outside the **International Space Station**, achieving technical readiness level 7 for its technology.

In September, **NASA** confirmed its decision to cancel **OSAM-1**, the planned On-Orbit Servicing, Assembly, and Manufacturing 1 satellite servicing and refueling mission. After the cancelllation was initially announced in February, Congress directed NASA to create continungency plans for carrying out a descoped version of the mission. Last year, NASA concluded a similar mission, **OSAM-2**, also without a flight demonstration. In September, NASA announced that it would provide lessons from OSAM-1 to DARPA to assist with that agency's **Robotic Servicing of Geosynchronous Satellites program**, which aims to demonstrate inspection, relocation, upgrade installation and anomaly correction of GEO satellites.

In January, **NASA's Precision Assembled Space Structure program** completed ground demonstrations of large-scale, neural-network-assisted truss assembly, working toward a planned ground demonstration to assemble a 20-meter diameter telescope.

Interest in space robotics from all sectors continued to grow. In January, the **U.S. Space Force** and **Air Force Research Laboratory** announced it would award contracts to the **University of Cincinnati** and **Texas A&M University** under the **Space Strategic Technology Institute 2** initiative. In August, NASA announced its Early Career Initiatives awards, with two projects focused on in-space robotics: the **Modular Assembled Radiators for Nuclear Electric Propulsion Vehicle** and **Lunar Assembly and Service by Autonomous Robotics**.

In the area of robotic subsystems and capabilities, the first space-hardened **artificial intelligence-focused graphics processing unit** was launched in August in a computer built by **Aethero** of North Dakota. Aethero, with **Cosmic Shielding Corp.** of Georgia, demonstrated on-orbit GPU processing capabilities.

Space-based computer vision had a surge of activity, with the May opening of the **Center for Aerospace Autonomy Research** at **Stanford University**, in partnership with Blue Origin and Redwire), and the founding of startups including **Space-ng** of California.

In proving itself as the new frontier for space exploration and operations, space robotics will continue to grow in importance, relevance and market. ★

Contributors: *Cesare Guariniello and Kimberly Wilcher*

Navigating challenges and fueling growth in space logistics capabilities

BY HAO CHEN AND PAUL GROGAN

The **Space Logistics Technical Committee** fosters development of integrated space logistics capabilities that enable safe, affordable and routine spacefaring operations.

As the demands for advanced space logistics capabilities surged, governments and companies worldwide responded with ambitious initiatives and substantial funding. However, these efforts were not without hurdles. In March, NASA announced it would cancel **OSAM-1**, the $2 billion **On-orbit Servicing, Assembly, and Manufacturing** project that planned to test refueling the **Landsat-7** satellite. NASA attributed the decision to cost overruns and schedule delays after a continuation review conducted by an independent review board. Just days later, Congress in the final fiscal 2024 appropriations bill directed NASA to continue with an adjusted OSAM-1 mission, fully funding the project at $227 million for a 2026 launch. Despite this, NASA said in September it planned to proceed with OSAM-1's cancellation.

In February, the U.S. **Federal Communications Commission** proposed a new regulatory framework for licensing commercial **in-space servicing, assembly and manufacturing operations**, aligning with the **White House's ISAM National Strategy** released in April 2022.

Meanwhile, government and commercial investments continued to drive rapid development of **in-space logistics** capabilities. In January, industrial conglomerate **Marubeni Corp.**, one of Japan's largest trading companies, led a $110 million Series C round for **D-Orbit**, an Italian space logistics service startup, to support its expansion into satellite servicing, space cloud computing and debris removal. This was among the largest funding rounds for a European space tech company. In June, **NASA** awarded **SpaceX** an $843 million contract to build the **U.S. Deorbit Vehicle** for deorbiting the **International Space Station** after the end of its operations in 2030.

For work on **lunar surface logistics**, NASA in April selected **Intuitive Machines** of Texas, **Lunar Outpost** of Colorado and **Venturi Astrolab** to complete feasibililty studies for their designs of a lunar terrain vehicle, with milestone-based contracts valued up to $4.6 billion. NASA plans to fund the development of one LTV, which astronauts will operate beginning with the Artemis V mission in 2029. In May, NASA selected the **Jet Propulsion Laboratory's FLOAT** concept for the first lunar surface railway system to move onto phase two of the **Innovative Advanced Concepts program**. Also in May, **Redwire** of Florida received a contract from the **European Space Agency** to develop a prototype of the robotic arm **MANUS, Manipulator for Argonaut Payload Needs and Unloading System.** MANUS is to ride to the moon aboard the Argonaut lander and assist in retrieving cargo and positioning science instruments, among other tasks.

In the realm of defense, the **Defense Innovation Unit** in March awarded contracts to **Blue Origin, Northrop Grumman and Florida-based SpaceBilt** to develop and demonstrate prototypes of spacecraft for on-orbit refueling and in-space assembly and manufacturing. These contracts are part of a larger effect to enable operations beyond low-Earth orbit. In the same month, **DARPA** awarded a contract to **Northrop Grumman** to continue developing its concept for a lunar railroad network system as part of DARPA's **10-year Lunar Architecture Capability Study**. In August, the **U.S. Air Force** awarded **Outpost Technologies Corp**. of Alabama a $1.25 million contract to develop its Ferryall and Carryall reentry vehicles. Specifically, the Air Force is interested in the ability to "warehouse" cargo on orbit for on-demand delivery to any location on Earth.

In academia, the **Space Force**, in partnership with the **Air Force Research Laboratory**, in January awarded two cooperative agreements for the **Space Strategic Technology Institute 2** led by **Texas A&M University** and the **University of Cincinnati**, for researching technologies related to in-space mobility, logistics and robotic servicing. Texas A&M will receive up to $37.6 million, and the University of Cincinnati up to $11.5 million ★

▼ Lunar Outpost of Colorado is among the companies NASA has contracted to develop and refine concepts for a Lunar Terrain Vehicle that astronauts would drive over the lunar surface. Lunar Outpost's concept is pictured here in an artist rendering.

Lunar Outpost

Tests and technology development push in-situ resource utilization forward

BY DAVID DICKSON AND ROBERT MOSES

The **Space Resources Technical Committee** advocates affordable, sustainable human space exploration using nonterrestrial natural resources to supply propulsion, power, life-support consumables and manufacturing materials.

▲ NASA in April flew the Ultrasonic Blade Experiment Rack aboard a parabolic aircraft to test a technique for excavating regolith on the moon or Mars. UBER consists of a vibrating knife that was inserted into lunar regolith simulant. The vibrations are meant to reduce the amount of force required to extract the regolith.

NASA's Glenn Research Center/Phillip Abel

In July, NASA stopped development of its **Volatiles Investigating Polar Exploration Rover**, which was to prospect the lunar south polar region for water and other volatile resources. NASA attributed its decision to projected cost increases related to lander delays and other budget considerations in its **Science Mission Directorate** portfolio. NASA released a request for information for industry proposals to take over VIPER, which it was assessing as of November.

In August, the **NASA ISRU Pilot Excavator, IPEx,** completed a five-day Technology Readiness Level 5 milestone, during which it operated around the clock in a simulated lunar autonomy testbed at the Swamp Works lab at **NASA's Kennedy Space Center** in Florida, with operators monitoring from a remote-control room. IPEx completed the full mission, which included 334 excavation cycles (equivalent to 10,000 kilograms of excavated regolith), some 58 kilometers of driving, and 35 autonomous dockings to a simulated wireless charger.

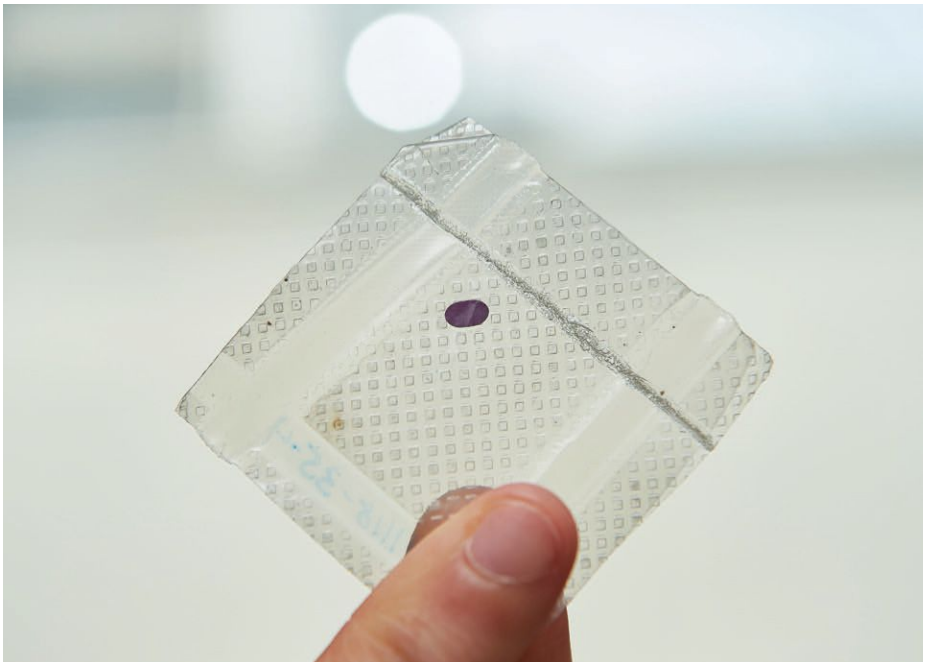
In April, **NASA's Glenn Research Center** in Ohio, with **Concordia University** in Canada, flew the **Ultrasonic Blade Experiment Rack** payload aboard two parabolic flights to investigate tool force-reduction capabilities of resonantly vibrating tools in lunar regolith simulant. While aboard the G-FORCE-ONE aircraft operated by **Zero-G Corp.**, researchers studied the insertion of a blade resonantly vibrating at 20 kilohertz and assessed the impact on observed forces on the blade at lunar and Martian gravities, with and without active vibration of the blade. The work is part of an effort to develop next-generation technologies for **exploration and resource extraction** on the moon and Mars.

In June, two teams were awarded $1.5 million in **NASA's Break the Ice Lunar Challenge**. **Terra Engineering** of California took home the top prize for its **Fracture rover**, a potential solution for autonomous lunar excavation. **Starpath Robotics** of California earned second place for its multifunctional rover designed for mining and hauling. The design included a drum barrel scraping mechanism that would allow the robot to mine material quickly, robustly and efficiently.

In April, the **U.S. Department of Energy** selected **Blue Origin** to receive a **Revolutionizing Ore to Steel to Impact Emissions** contract to develop technologies for reducing the ecological impact of terrestrial steel production. Blue Origin received $1.1 million for its **Ouroboros** reactor, which the company is developing to produce high-purity iron from low-quality ores with zero greenhouse gas emissions. In July, startup **Interlune** of Washington received a contract award in July through **NASA's TechFlights solicitation** to develop its technology for extracting lunar volatiles, including **helium-3**.

In April, researchers at **McGill University** in Canada, the **University of Texas at El Paso** and **Seoul National University** completed a conceptual design of rocket engines that run on regolith-derived propellants, such as oxygen, metal alloys and sulfur obtained from lunar regolith. Also in April, the **University of Central Florida** opened two large-scale **regolith simulant testbeds** for testing of lunar rovers and other equipment, with optional gravity offloading provided via an overhead crane. This testbed hosted the qualifying rounds of the **2024 NASA Lunabotics** robotic mining competition and will host the 2025 qualifiers. In August, Sierra Space completed thermal vacuum tests of the Carbothermal Oxygen Production Reactor at NASA's Johnson Space Center, demonstrating the reduction of a single regolith melt by methane and measurement of produced carbon dioxide. In November, the Colorado School of Mines opened a 100-square-meter lunar testbed, funded by a NASA LuSTR grant and available for commercial technology development. ★

Contributors: *Phillip Abel, Anthony Colaprete, Chris Dreyer, Amelia Grieg, Michael Hecht, Shaspreet Kaur, Jared Long-Fox, George Lordos, Erin Rezich, Evgeny Shafirovich, Laurent Sibille and Paul Van Susante*



Progress toward making future space communities possible

BY BRYCE L. MEYER

The **Space Settlement Technical Committee** promotes the identification and development of advanced concepts, science, and technology that will support, enhance and enable permanent human presence in space.

▲ This purple dot is a retinal implant manufactured by LambdaVision aboard the International Space Station. The Connecticut pharmaceutical company says the implants are easier to produce in microgravity.

University of Connecticut/Peter Morenus

Space settlement requires developing several seemingly disconnected technologies that will eventually be synergistic. This year, these efforts and technologies took a step forward.

The first two missions under **NASA's Commercial Lunar Payload Services program** began. In February, an **Intuitive Machines Nova-C lander** touched down near the moon's south pole, though it tipped over shortly after. The lander carried a few settlement-related experiments, including cloth from **Columbia Sportswea**r of Oregon that could be used for heat-rejection covers, the **Stereo Cameras for Lunar Plume-Surface Studies** experiment, with which researchers aim to determine the effects that the plume created by a descending lander would have on nearby settlements. In January, **Astrobotic's Peregrine lander** was launched, but an onboard helium leak overpressurized the oxygen tank, preventing the lander from reaching the lunar surface. Also in January, **JAXA, the Japan Aerospace Exploration Agency**, landed its **Smart Lander for Investigating Moon**, which included precision landing technology and two rovers to collect data. All three attempts could help refine plans for delivery missions to future lunar settlements.

Space settlements will need to be constructed before they can be inhabited, and in March, **ICON** of Texas unveiled a robot that can print full-scale buildings on Earth. The robot could be adapted to use in situ materials to 3D-print buildings on Mars or the moon under **NASA's Project Olympus.**

Getting goods back to Earth cheaply from space will be critical for future space settlements, especially in-space factories that could manufacture electronics, pharmaceuticals or human replacement tissues. In June, China's **Chang'e-6** capsule returned 4 kilograms of drilled and scooped regolith from the lunar far side. As of January, **LambdaVision** of Connecticut had returned its 10th retina manufactured aboard the **International Space Station.** That month, the NG-20 Cygnus spacecraft launched ISS carrying Lambda's latest protein-based materials for retina construction. Microgravity enables tissue engineering far better than on Earth.

In June, the **U.S. Space Force** awarded a contract to **General Atomics** of San Diego for the **Enterprise Space Terminal project** to establish a **mesh-based laser communications network** beyond low-Earth orbit. One day, this network could provide bandwidth for orbital factories and orbiting settlements.

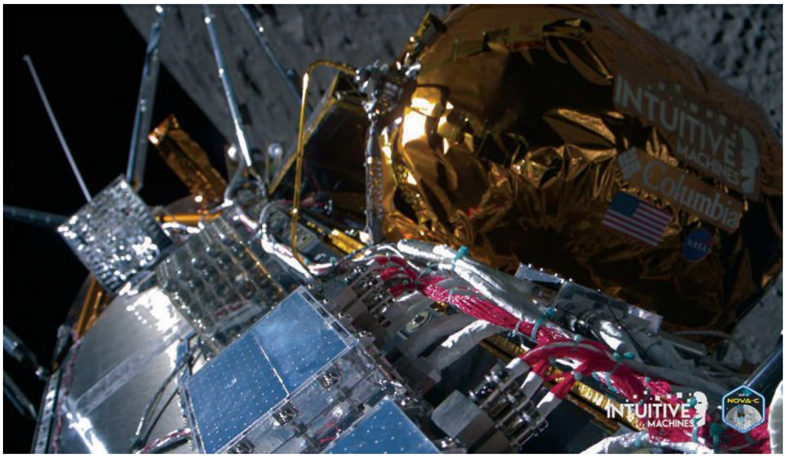
Powering these settlements and propelling spacecraft to and from them will likely require **nuclear power** as one power source. In July, Lockheed Martin described one vision for a water-based, nuclear-powered settlement in a novella, "A Vision for Humanity's Future in Space." Additionally, workshops hosted by the American Nuclear Society and NASA explored how nuclear power could be used in space. The ANS **Nuclear and Emerging Technologies for Space workshops** in May covered **fission power** for lunar and Martian bases, power for **electric space propulsion**, and **nuclear thermal propulsion**. The **NASA Fission Instrumentation and Controls Workshop** in August covered similar topics — a fission surface power system and space nuclear propulsion technologies. In both gatherings, nuclear was shown to have promise for transportation to and from settlements and keeping the lights on at bases and factories. In September, it was reported that Russia, China and India have agreed to research nuclear reactors on the moon to power future lunar bases.

These efforts are the pieces that will help fill the puzzle that allows humans to permanently live in space. ★

Technology for satellites and human spaceflight advances, as commitments to mitigating space debris strengthen

BY SMRITHI KEERTHIVARMAN

The **Space Systems Technical Committee** fosters the development, application and operation of space systems, and addresses emerging issues in the area.



▲ In February, Intuitive Machines' Nova-C Odysseus became the first U.S.-built spacecraft to touch down on the moon since 1972. The lander touched down in the south pole as planned, though range altimetry was briefly lost during its descent and Odysseus fell over on its side shortly after. It operated for seven days and transmitted data from all five of its active payloads.

Intuitive Machines

There was progress this year toward advancing different classes of proliferated satellite constellations and taking ownership of orbital debris mitigation. In renewed pursuit of the moon and beyond, uncrewed landers achieved unprecedented feats, though challenges still persist in human-rated spacecraft.

Closest to home, the realm of **very low-Earth orbit** (250-350 kilometers) gained attention for its promise to boost data resolution and low-latency communication. At lower altitudes, atmospheric drag and high atomic oxygen concentrations pose spacecraft design challenges and necessitate aerodynamic and material considerations. In June, **DARPA** and the **European Space Agency** selected **Redwire** of Florida to develop and demonstrate a modular VLEO spacecraft with novel air-breathing capabilities by 2027.

In LEO, advancements included the January launch of SpaceX's first **Direct-to-Cell Starlink** satellites. The antenna and software onboard enabled an unprecedented connection from space to a mobile phone on Earth. August marked the first-ever Link 16 military network entry to a U.S. Navy ship from space, via one of the Space Development Agency's **Tranche-0** satellites. This **Proliferated Warfighter Space Architecture** milestone could help lead to beyond-line-of-sight communications worldwide in near real time.

The trend of disaggregating traditional multiton satellites also extended to geostationary orbit. The **Space Force** announced in March that its **Protected Tactical SATCOM-Global program** will spend $248 million in fiscal year 2025 toward analyzing small maneuverable GEO satellites to boost resilience and communication capabilities.

Coupled with a burgeoning satellite population, derelict and abandoned spacecraft pose a growing risk of orbital collisions, as demonstrated in August by the breakup of Chinese **Long March 6A upper stage** that generated some 300 pieces of trackable debris. Crucial to mitigating such events is the development of autonomous spacecraft to characterize and deorbit large debris. Launched in February, **Astroscale's ADRAS-J** spacecraft became the first to approach and image a piece of debris — in this case, an abandoned Japanese upper stage — via visible and infrared cameras and laser ranging sensors. In August, **JAXA, the Japan Aerospace Exploration Agency**, awarded Astroscale an $81 million contract to capture and deorbit the stage by 2029. The **Indian Space Research Organisation** also demonstrated its commitment to mitigating debris by deorbiting **Cartosat-2** in February and facilitating early reentry of **XPoSat's terminal stage** in March. Other innovative solutions that have been launched include **Airbus' Detumbler** based on electromagnetic brakes and Japan-based **LignoSat's wooden frame** that would minimize atmospheric pollution during burn-up.

NASA's effort to return to the moon marked a milestone in February when **Intuitive Machines' Nova-C Odysseus** landed in the lunar south pole, though the lander fell sideways shortly after. NASA continued to analyze the unexpected **Orion** heat shield erosion from the 2022 Artemis I test and make preparations for the **Artemis II** crewed lunar flyby, scheduled for 2025. In a first for humanity, China's **Chang'e-6** capsule in June returned samples from the far side of the moon.

In human spaceflight, a **Boeing Starliner capsule** carried two astronauts to the **International Space Station** in June for the long-awaited Crew Flight Test. With lingering concerns about Starliner's helium leaks and thruster degradation, NASA decided to return the unoccupied capsule in September and return the astronauts in February 2025 aboard a **SpaceX Crew Dragon**. In September, the first private spacewalk was conducted during the five-day Polaris Dawn mission, following delays due to SpaceX grounding its **Falcon** rockets for the second time this year.

Fascinating scientific discoveries continued to further the search for potential life outside Earth. Most notably, the latest analysis of seismic data from **NASA's Mars InSight lander** indicates there is a large reservoir of liquid water 10-20 km below the surface. Other findings included the detection of molecular water on asteroid surfaces by isolating mid-infrared spectral signatures, and the atmospheric detection of water vapor in the **exoplanet GJ 9827d**, as observed by the **Hubble Space Telescope**. ★

Contributors: *John Bloomer and John Carsten*

Researchers refine tether technologies for commercial use

BY SVEN BILÉN

The **Space Tethers Technical Committee** focuses on the development and use of tether-based technology for space systems.

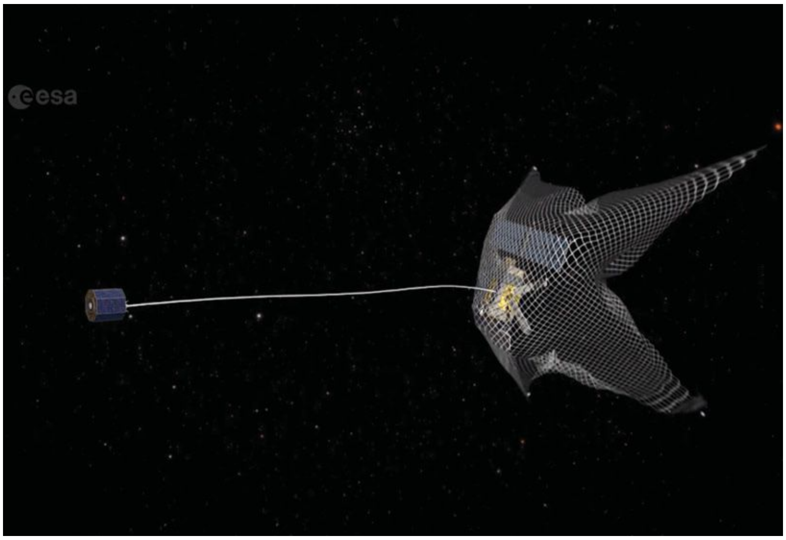
The space tethers community made strides toward space debris removal, more efficient orbital propulsion and deeper exoplanetary exploration.

In April, researchers at the **University of Colorado at Colorado Springs** designed the first mission in which a tethered spacecraft would image an exoplanet. Working with **NASA's Jet Propulsion Laboratory** in California, they combined a **solar gravitational lens** technique with tether dynamics, allowing a spacecraft to sample the image plane of a distant planet in the optical spectrum without the need for onboard propellant for the relative motion station-keeping. Their work on tether deployment and vibration control could enhance long-duration missions for exoplanetary exploration.

In the area of debris removal, researchers at the **University of Buffalo** in New York, funded by the **U.S. National Science Foundation**, reported in January on their model of a **net-based tether**, with promising results in terms of safe target capture and system efficiency. In May, they overviewed their advanced control systems for **robotic tether nets**, using learning-aided techniques to improve target capture even under difficult conditions. Researchers at **Tokyo Metropolitan University** also made strides in tether-net capture technology. In February, they reported their simulations and experiments on optimal collision points for tether-net entanglement with debris. Their work, which involved modeling the net as a spring-mass-damper system, offered new strategies for debris mitigation.

Researchers at the **Beijing Institute of Technology**, funded by China's National Natural Science Foundation, have developed detumbling strategies for underactuated tethered satellites. In January, they proposed a robust detumbling method based on **hierarchical sliding mode control**. In July, they developed a **tension regulation method** that's capable of detumbling a target as well as suppressing the tether libration for active debris removal missions.

As of October, the testing campaign of the engineering qualification model of a deorbit device was nearing completion under the **Electrodynamic Tether Technology for Passive Consumable-less Deorbit Kit-Fly project**. Funded by the European Innovation Council, the **E.T.PACK-F consortium** is coordinated by the **Universidad Carlos III de Madrid** in collaboration with the **University of Padova** in Italy, the **Technical University of Dresden** in Germany, Spanish company **SENER Aeroespacial** and German startup **Rocket Factory Augsburg**. The team plans to fly its 12-unit, 24-kilogram deorbit device in 2025 or 2026.



▲ Several research groups continued investigating the viability of net-based tethers for capturing and removing orbital debris.

European Space Agency

In October, the **Compact and Propellant-less Electrodynamic Tether System Based on In-Space Solar Energy project** began, with funding from the European Innovation Council. Coordinated by **Universidad Carlos III de Madrid** — in collaboration with the **University of Padova**, the **Technical University of Dresden**, the Spanish company **DEIMOS Engineering and Systems**, Italy-based **Halocell Europe** and the Austrian company **Sunplugged** — the E.T.COMPACT project is to study thin-film two-terminal tandem Perovskite-CIGS solar cells for installation on an ultra-compact propulsion system based on bare-photovoltaic tether technology.

At the **University of Strathclyde** in Scotland, researchers were active on three fronts. They advanced **symbolic computation programs** for analyzing motorized tethers with varying mass asymmetries, building a library of code variants that can assess on-orbit performance. Work concluding in June explored miniaturizing **motorized momentum-exchange tethers** for raising the orbits of nanosatellites. Researchers discovered that while the technology shows promise, energy density constraints remain a limiting factor. In August, they completed an analysis of the cost savings of using a motorized tether to propel a 50-kilogram payload from low-Earth orbit. ★

Record pace continues in space launch

BY DALE ARNEY

The **Space Transportation Technical Committee** works to foster continuous improvements to civil, commercial and military launch vehicles.

In April, **SpaceX** completed the 300th successful landing of a **Falcon** booster. In late October, SpaceX conducted the 100th Falcon launch this year, surpassing its 96 launches in 2023. Despite these milestones, it wasn't a flawless year for Falcon. The design was grounded briefly in July and August as SpaceX investigated two mishaps. The first, in July, stemmed from an **oxygen leak** in the **Falcon 9 upper stage** during a launch from Vandenberg, California. The stage's engine didn't complete its second firing, so the **Starlink** satellites it carried didn't reach their target altitude. This ended a streak of some 300 successful launches dating back to 2016, approximately three times longer than any other rocket. The second grounding came in late August, when a booster tipped over shortly after landing on the **A Shortfall of Gravitas droneship**. That booster had flown 23 times.

In mid-November, SpaceX launched its six **Starship-Super Heavy** rocket. During the fourth flight test in June, controlled splashdowns with both stages were achieved for the first time. During the fifth flight in, a Super Heavy returned to the launch site into the mechanical arms of the launch tower, and Starship made a controlled splashdown in the Indian Ocean.

In May, **Blue Origin** resumed crewed flights with its suborbital **New Shepard** rocket and capsule after a nearly two-year hiatus. The company also progressed toward the first flight of a **New Glenn** heavy-lift rocket, conducting cryogenic testing in March with a flight-capable booster and upper stage test article.

In April**, United Launch Alliance** launched the 16th and final **Delta IV Heavy**, culminating a 64-year program that comprised 389 launches. In July, ULA completed its final national security launch with an **Atlas V**. In January, ULA launched its inaugural **Vulcan Centaur** from **Cape Canaveral Space Force Station** in Florida. The second Vulcan was launched in October, clearing the design to begin national security launches pending a Space Force review.

Europe also debuted a new rocket. In July, the first **Ariane 6** was launched from French Guiana.

In June, **Rocket Lab** launched its 50th **Electron** rocket from its New Zealand facility. In August, Rocket Lab test-fired its new **Archimedes** engine at **NASA's Stennis Space Center** in Mississippi, a step toward developing its medium-lift **Neutron**, scheduled to debut in 2025.

In human spaceflight, **NASA** continued preparations for its **Artemis II** crewed lunar flyby, scheduled for 2025. In July, the second **Space Launch System** core stage arrived at **NASA's Kennedy Space Center**. NASA also conducted a 500-second test fire of an **RS-25** engine in January, the design that is to propel a more powerful version of SLS rockets starting with the **Artemis V** lunar landing in 2029.

In March, a **SpaceX Crew Dragon** capsule delivered its eighth astronaut crew to the International Space Station under NASA's Commercial Crew Program. In June, two astronauts launched in a **Boeing Starliner** capsule for the design's crewed flight test. While en route to the **International Space Station**, Starliner experienced helium leaks and thruster degradation, so NASA decided to return the unoccupied capsule in September. The astronauts will return in February aboard a Crew Dragon.

In June, **Virgin Galactic** conducted its final suborbital flight with the **VSS Unity** spaceplane, flying four passengers in the Galactic 07 mission.

In May, the **Indian Space Research Organisation** hot fired a **PS4** engine with 3D-printed parts, intended for use on its **Polar Satellite Launch Vehicle**. In August, India's **Small Satellite Launch Vehicle** achieved its third launch, lofting an experimental Earth-observation satellite. And in February, the **Japan Aerospace Exploration Agency, JAXA,** conducted the first successful launch of an **H3** rocket, after the second stage engine failure that occurred during the design's inaugural flight test last year. ★

▶The first Ariane 6 rocket was launched in July from French Guiana. Aboard were several experiments and a handful of cubesats from universities and companies in Europe and the U.S.

ESA/S. Corvaja

Missile defense, hypersonics and high-energy lasers versus drones

BY JAMES D. WALKER

The **Weapon System Effectiveness Technical Committee** advances the science and technology of predicting, measuring, evaluating and improving the lethality of weapon systems.

▲ In a February test off the coast of Hawaii, the Missile Defense Agency and the Navy launched a missile from an Aegis-equipped ship, which intercepted and destroyed the medium-range ballistic missile at the center of this photo. The parachutes at right hold the rail that the missile was attached to when it was released from the back of a C-17 aircraft.
Missile Defense Agency

In February, the **U.S. Missile Defense Agency (MDA) and U.S. Navy** conducted **Flight Test Other-23**, a two-part test of sensor tracking and communications links off the coast of the Pacific Missile Range Facility in Hawaii. In the first part, they demonstrated that the **Aegis Weapon System** could track and discriminate a complex target — in this case, a countermeasure-equipped medium-range ballistic missile air-launched from a C-17 over the Pacific Ocean. A **Standard Missile-3 Block IIA** launched from the Aegis intercepted the target, which MDA described as "one of the most complicated target discrimination and intercept missions by the Aegis Weapon System to date."

Also in February, a **SpaceX Falcon 9** rocket delivered into low-Earth orbit the first two **Hypersonic and Ballistic Tracking Space Sensor satellites**, a joint program of MDA and the Space Development Agency, SDA. Also aboard were the final four **Tranche 0 Tracking Layer** satellites for SDA's planned **Proliferated Warfighter Space Architecture** constellation. In June, the HBTSS prototypes monitored the first flight of the **Hypersonic Test Bed**, a Kratos-built vehicle designed to provide a common platform for hypersonic experiments. For that flight, HTB-1, the Erinyes vehicle was launched from **NASA's Wallops Flight Facility** in Virginia. Sensors on the HTBSS satellites collected data after launch as the vehicle was propelled to hypersonic speeds. Data was also collected on numerous experiments, both internal and external, allowing relevant testing in a hypersonic environment.

In April, **MDA** awarded **Lockheed Martin** a contract worth up to $17 billion for the **Next Generation Interceptor, NGI,** the updated missiles for the **Ground-based Midcourse Defense** segment that will intercept incoming missiles during an exo-atmospheric hit-to-kill interaction. They are to replace today's Boeing-developed interceptors at Fort Greely in Alaska and Vandenberg Space Force Base in California, and their development is a response to developments in adversary ballistic missile systems in which other countries are developing missiles that appear more mobile, survivable, reliable, accurate and longer-ranged. Each NGI will carry multiple **kill vehicles**, allowing for multiple impact events on one incoming missile or potentially interaction with multiple targets by each missile.

In April, U.S. **directed energy weapons** were deployed overseas for the first time. The Army fired its **P-HEL, Palletized High Energy Laser,** in an undisclosed location. The service did not disclose whether any of the targers were hit, but marked a milestone in the development of high-energy lasers that has been ongoing for many years. The P-HEL laser and its packaging, based on the **LOCUST Laser Weapon System** by **BlueHalo** of Virginia, is 1.2 meters wide, 2.2 m long and 2.1 m high. Including the weight of radar and other supporting equipment, P-HEL weighs 1,540 kilograms, and the laser has a power range of 2-20 kilowatts. The software for tracking and ensuring the beam hits and stays on target is a key feature of the integrated capability.

Finally, ballistic missile defense systems of the West performed well when extensive sorties of missiles were launched by Iran on two separate occasions. ★

Preparing for new airspace entrants

BY FRANK L. FRISBIE AND CHARLIE KEEGAN

The **Aerospace Traffic Management Integration Committee** monitors, evaluates and seeks to influence the direction of ATM technologies with a focus on efficiency, public safety and national security.

▲ National Transportation Safety Board investigators examine the door plug that fell off Alaska Airlines Flight 1282 shortly after the Boeing 737-9 MAX departed from Portland. Three of the 177 aboard were treated for minor injuries after the pilots completed an emergency landing.

NTSB

Events early in the year illustrated the continued fragility of the aging **U.S. National Airspace, NAS**, infrastructure, as well as the growing complexity presented by current aircraft and coming classes of new aircraft. Among the prospective entrants is **Joby Aviation**, a California air taxi developer that in February announced it completed three of the five stages toward achieving FAA type certification of its S4 **electric vertical takeoff and landing** aircraft. Joby and other developers are targeting as early as 2025 for beginning passenger flights, although some of these flights would require infrastructure — specifically vertiport takeoff and landing pads — that does not yet exist.

Further evidence of growth came in July, when **FAA** authorized multiple operators to fly commercial drones **beyond visual line of sight, or BVLOS**, in the same airspace. **Zipline International** and Alphabet subsidiary **Wing** delivered packages to Walmart customers in the Dallas/Fort Worth, Texas, area, keeping their drones safely separated via **Unmanned Aircraft System Traffic Management, or UTM, technology**.

At the same time, FAA continued to craft initial rules that would allow routine BVLOS flights operations "while maintaining the same high level of safety as traditional aviation," the agency said in a press release. As of November, this **Normalizing UAS BVLOS Notice of Proposed Rulemaking** was scheduled to be published in the Federal Register by the end of the year.

Turning to commercial aviation, an **Alaska Airlines** flight in January was cut short when the rear door plug of a **Boeing 737 MAX 9** fell off, prompting FAA to ground the nearly 200 MAX 9s operated by U.S. airlines. This also triggered an investigation by the **National Transportation Safety Board** and increased FAA oversight of Boeing's quality control processes and requirements for their correction. Among the actions, FAA directed Boeing to submit a "comprehensive action plan" for increasing safety and initiated monthly reviews of the company's progress.

Also in January, U.S. Reps. Robert Garcia (D-CA) and Glenn Grothman (R-WI) introduced the **Safe Airspace for Americans Act**, which would direct FAA to "establish procedures and reporting requirements" for pilots and other civil aviation personnel to report **unidentified anomalous phenomena** encounters to FAA.

In July, tens of thousands of U.S. flights were canceled or delayed when cybersecurity company **CrowdStrike** sent out a faulty software update that caused computers operating Microsoft Windows to go down. **Delta Air Lines'** operations were disproportionately affected due to its heavy reliance on the software, but FAA's systems were unaffected. The experience exposed the vulnerability of aviation to shared information sources without reliable backup.

In September, Australian startup **Skykraft** announced the completion of thruster tests for its planned air traffic surveillance constellation. The company is targeting 2026 to begin providing global controller-pilot communications, services that are today offered by Aireon.

On the topic of workforce, FAA in February announced the creation of an **Enhanced Air Traffic-Collegiate Training Initiative program,** in which trained college students could proceed directly to training at an FAA facility. This is among the steps FAA has taken in recent years to address the ongoing shortage of air traffic controllers, but the chronic gaps persist.

Another recurring problem is aging infrastructure. Various parts of the NAS are over 40 years old, with replacements decades away. FAA identifies the shortfall "gap" at $2.175 billion to fully address these needs. As part of its fiscal 2025 budget released in March, the Biden administration proposed dedicating $8 billion over the next five years, with $1 billion for fiscal 2025. This **Facility Replacement and Radar Modernization effort** "includes modernizing 377 critical radar systems and more than 20 air traffic control facilities," FAA said in a press release. ★

Creating ever-more-sophisticated simulations

BY UMESH PALIATH, JEFF SLOTNICK AND ANDREW WISSINK

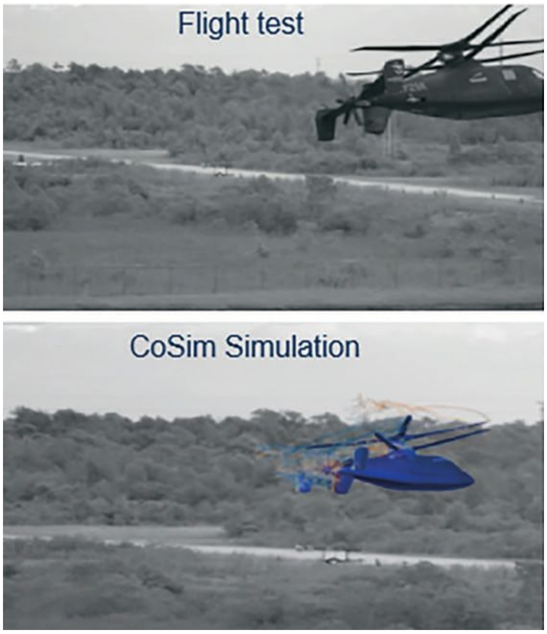
The **CFD Vision 2030 Integration Committee** advocates for, inspires and enables community activities recommended by the vision study for revolutionary advances in the state-of-the-art of computational technologies needed for analysis, design and certification of future aerospace systems.

In August, the fifth **High Lift Prediction Workshop** was attended by a large gathering of computational fluid dynamics practitioners from government, industry, academia and commercial interests. With the continued goal of enhancing **CFD prediction capability** for practical high-lift aerodynamic design, attendees worked on test cases focused on solution verification, the prediction of configuration build-up and Reynolds number effects, all using the **CRM-HL, or High Lift Common Research Model**, reference geometry. To anchor the CFD results, researchers applied experimental data from testing of CRM-HL to ONERA's 5.1% full-span model in the French space agency's F1 facility. Among the outcomes: When properly verified and fully iteratively converged, **Reynolds-Averaged Navier-Stokes** simulations on families of best-practice meshes for the simpler CRM-HL configurations generated **mesh-converged solutions** that are consistent with RANS solutions obtained with mesh adaptation. Additionally, CFD efforts continued to focus on the maturation of scale-resolving simulation methods, like **Wall-Modeled Large Eddy Simulation** and **Hybrid RANS-LES** technology. The scaled resolved simulations showed more consistent improvement in the prediction of subsonic maximum lift over other methods using meshes of roughly a billion degrees of freedom. However, results indicated that these methods are not appropriately modeling leading-edge slat boundary layer transition and low angle-of-attack flap flow separation. Researchers anticipate that predictive capabilities will improve as lessons from future CRM-HL testing are incorporated to refine modeling best practices.

A key milestone of the **CFD Vision 2030 study** was to demonstrate **efficiently scaled CFD simulations** on an exascale system. As these platforms have come online at U.S. Department of Energy laboratories over the past two years, multiple CFD applications have leveraged these resources to showcase CFD predictive capabilities. This year, two breakthroughs occurred on the **Frontier exascale machine at Oak Ridge National Laboratory** in Tennessee. First, the **FUN3D** development team from **NASA's Langley Research Center** in Virginia worked with **NASA's Ames Research Center** in California, **Analytical Mechanics Associates** of Virginia and **Old Dominion University** in Virginia to perform full-system simulations. Applications included real-gas simulations of retro propulsion for a human-scale Mars lander concept and simulations of the CRM-HL. In March, **GE Aerospace** simulated a full-scale Open Fan Blade at real-world flight conditions as part of **CFM International's RISE, or Revolutionary Innovation for Sustainable Engines, program**. This simulation gave engineers an enhanced view into the complex turbulent flow at a microscopic level to guide aerodynamic and aeroacoustic design. These high-fidelity simulations yielded information that would otherwise take scientists years to gather. The problem size of these simulations is of the order of hundreds of billion grid points and have been demonstrated to run efficiently on greater than 90% of the Frontier machine.

Another achievement involved the development of **high-fidelity co-simulation technology** for free-flight full-aircraft maneuvers, using closed-loop tightly coupled CFD and **computational structural dynamics, CSD,** with full-production aircraft flight control systems. **Sikorsky** created a virtual prototype of its **S-97 Raider X** rotorcraft by integrating its proprietary flight controls software with the **Department of Defense's Helios high-fidelity rotary-wing simulation code**. Helios was developed under the **High Performance Computing Modernization Program's Computational Research and Engineering Acquisition Tools and Environments program**. With its virtual S-97 prototype, Sikorsky validated the model against flight test data from a real-world vehicle, demonstrating that the high-fidelity CFD model was able to achieve comparable accuracy to flight. In May, the **Vertical Flight Society** presented the team with the **2024 Howard Hughes award** for this work. ★

Contributors: *Reynaldo J. Gomez III and Eric Nielsen*



▲ Sikorsky created a virtual prototype of its in-development S-97 Raider X rotorcraft to verify that the software could replicate the results of real-world flight tests. In this snapshot of one simulation, the prototype is banking at a 60-degree angle.

Sikorsky

NASA, European Space Agency go for Jupiter's moons

BY LEENA SINGH AND SURENDRA P. SHARMA

The **Space Exploration Integration Committee** brings together experts on topics relevant to future human and robotic exploration missions.

▲ The European Space Agency's Juice spacecraft, short for Jupiter Icy Moons Explorer, completed an Earth-moon flyby, one of multiple fuel-saving manuevers planned as the spacecraft travels toward Jupiter. Juice's JANUS camera took this image on Aug. 19, about 700 kilometers from the lunar surface.

European Space Agency

In June, **NOAA's GOES-U**, the Geostationary Operational Environmental Satellites-U, was launched aboard a **SpaceX Falcon Heavy** rocket. The fourth of four **GOES-R series** weather and environment monitoring satellites, GOES-U will monitor the Western Hemisphere, including the Americas, the Caribbean and the Atlantic Ocean to western Africa. After a fortnight's transfer from delivery into geostationary transfer orbit, GOES-U was inserted into its checkout slot, about 35,700 kilometers altitude, and renamed **GOES-19**. Following an extended instrument checkout period that began in August, GOES-19 is to drift from checkout to its operational slot in 2025 to commence environmental monitoring with the rest of the GOES-R satellites. GOES-19 carries a new, highly sensitive **Compact Coronagraph-1**, which is to detect and characterize **solar coronal mass ejections** with high sensitivity, providing enhanced forecasting of impending geomagnetic storms on Earth.

In October, a **Falcon Heavy** launched **NASA's Europa Clipper** toward Jupiter's moon, Europa. The spacecraft left its assembly site at the **Jet Propulsion Laboratory** in California in May for launch preparations from **NASA's Kennedy Space Center** in Florida. At Kennedy, final assembly included the installation of a high-gain antenna and two 46-foot-long solar panels, whose deployments were individually tested within Kennedy's clean rooms. Clipper will see temperatures below minus 240 degrees Celsius during eclipse in Jupiter orbit, so engineers combed through thermal and environmental hardiness test data collected in specialized cryogenic chambers deep into the year. Europa Clipper is equipped with nine science instruments that are to collect detailed measurements through the moon's icy crust during some 50 close flybys. Scientists have theorized a vast ocean is beneath Europa's icy crust, and Clipper's mission is to inspect Europa's crust for its thickness, composition and geology. Clipper is scheduled to arrive in orbit around Jupiter in 2030.

Adding to collision concerns of Earth's growing **orbital debris** volumes are environmental concerns from pollutants released into the stratosphere by reentering space objects. In February, the **U.K. Space Agency** awarded the **University of Southampton** the first "atmospheric ablation" research grant into potential climate, weather, astronomical and communications impacts from rocket bodies and defunct satellites disintegrating in the high atmosphere, releasing vast quantities of metal effluents. From multiple sample collection flights with a **laser mass spectrometer** onboard NASA's **WB-57** aircraft last year, **NOAA** scientists analyzed the 60,000-plus stratospheric particles collected. Their analysis, published in July in "Science" magazine, showed the world's first definitive evidence of **stratospheric pollution** from metal alloys that bear markers of spacecraft reentry.

In August, the **European Space Agency's Jupiter Icy Moons Explorer**, Juice, executed the first-ever **double gravity-assist maneuver** via another first, a **lunar-Earth flyby**, in a fuel-saving exercise to shortcut its rendezvous path to Jupiter's moons in 2031. Juice's near-perfect flyby execution demonstrated exquisite navigation and control precision and provided an opportunity to test its 10 scientific instruments. Among the instruments were the **JANUS science camera** and the **NavCam vision-navigation sensor**. NavCam will be critical for precise autonomous guidance, navigation and control in the Jupiter planetary system, and taking images of the flyby was an opportunity to conduct an early test of the sensors. After this double planetary assist, Juice is bound for a **Venus gravity-assist slingshot**, using a series of Venus-Earth/moon passes to save propellant.

Observations from **ESA's Solar Orbiter** and **NASA's Parker Solar Probe** processed this year answered long-standing questions about the source of energetics of solar winds. The two probes had intersected the same coronal stream from their distinct orbits one to two days apart; measurements of the time and space separated transits of the same phenomenon showed that energy gradients correlated to oscillations in the sun's magnetic field. This analysis dispels some of the mysteries about our sun. ★

Contributors: *Narayanan R. Ramachandran, Karen Rosenlof and Martin N. Ross*

Boom's demonstrator took flight, NASA continued X-59 preparations

BY DARCY L. ALLISON AND LORI OZOROSKI

The **Supersonics Integration Committee** promotes a community of practice engaged in the technical, business, environmental and societal issues associated with supersonic transports and the research needs of this emergent capability.

▲ Boom Supersonic this year began the inaugural flight campaign for its technology demonstrator, the XB-1. The aircraft in August conducted its second subsonic flight from the Mojave Air & Space Port in California.

Boom Supersonic

Boom Supersonic of Colorado continued toward its goal of reviving **supersonic passenger travel**. In March, the company's **XB-1** demonstrator completed its first flight, a subsonic mission. "Two decades after Concorde's retirement, the first flight of XB-1 marks the return of a civil supersonic aircraft to the skies and paves the way for the revival of mainstream supersonic travel," Boom said in a press release. The flights are to help validate the design of Boom's planned Mach 1.7 airliner, **Overture**, "while establishing a safety-first culture in engineering and manufacturing." In June, Boom held a ribbon-cutting ceremony at the **Overture Superfactory** to celebrate the completion of this facility at the Piedmont Triad International Airport in North Carolina. In July, at the **Farnborough International Airshow** in the U.K., Boom announced an all-new **Overture flight deck** that incorporates **Honeywell's Anthem avionics suite**, a **head-worn vision system from Universal Avionics** and **Active Control Sidesticks from BAE Systems**. Boom also described the progress on the **Symphony engines** that will power the Overtures and announced that the engines "will be assembled in San Antonio, Texas through an expanded agreement with StandardAero."

In January, **NASA** publicly unveiled its **X-59** demonstrator at **Lockheed Martin's Skunk Works** facility in California. As of October, integrated testing had begun, and the first engine runs were completed. Also in January, NASA completed a field test of the initial production versions of the high-fidelity microphones and other equipment that will measure X-59's sonic "thump" during the planned flights over select U.S. communities. Following this test, **Crystal Instruments** of California delivered the 70 units that will be used in the X-59 acoustic validation. A dry run of all the measurement techniques is planned for early 2025.

In November, a team led by the **University of Washington** — with **Stanford University**, the **University of Michigan** and **Boeing** — concluded a five-year study on the **applied aerodynamics** and **stability and control** of commercial supersonic transports in the low-speed regime. Their **Supersonic Configurations at Low Speeds project**, funded by NASA, included experimental and computational components. Researchers acquired some 1,000 data runs during 10 unique wind and water tunnel entries. This information now resides in a database meant to aid in future trade studies of supersonic airliner concepts, including their long, slender noses, upper mounted nacelles and three-surface control designs — unique features derived from low-boom shaping.

In February, NASA's exploration of commercial vehicles in the Mach 2-5 speed regime partially concluded with the delivery of final designs and analysis from the **Northrop Grumman** contract team. Though emerging **landing and takeoff noise regulations** and emissions remained a challenge, the team created a Mach 2 concept that satisfied the desired market range and passenger count identified in precursor studies, performed for NASA by **SpaceWorks Engineering Inc.** of Georgia. Northrop Grumman's concept for a **Mach 3 vehicle** required significantly more technologies embodied in a more radical configuration to satisfy these regulations, even at reduced range and passenger count. Also for this project, the **Boeing** team is on track to complete its **Mach 4 vehicle concepts** and technology road map by the end of the year. In their entirety, these studies are informing NASA's technical direction addressing the utility of high-speed flight.

In June, **NASA** completed the **Landing and Takeoff Noise Prediction Uncertainty Reduction**, a multiyear technical challenge. Researchers created **empirical noise models** tuned to predict the airport noise of near-term commercial supersonic aircraft. Through this effort, prediction uncertainty levels were reduced significantly and approached those for traditional subsonic aircraft. The new models will be made publicly available via **NASA's Technical Report Server**. ★

Contributors: *James Bridges, Peter Coen, Sarah Langston, Sahil Patel and Jon Seidel*

Gradual transformation of flight continues

BY KENNETH H. GOODRICH AND MICHAEL D. PATTERSON

The **Transformational Flight Integration Committee** serves as a focal point for a community of practice engaged in technical, business and societal issues associated with transformational approaches to on-demand air mobility enabled by the convergence of advanced technologies.

▲ Electra in July said its EL-2 Goldfinch hybrid-electric demonstrator completed takeoffs and landings from a 90-meter-long grass field, about three-quarters the size of a soccer field. The Virginia company said the goal was to simulate military flights "in a contested logistics environment."

Electra

The transformational flight sector continued to make strides toward scalable commercial operations, while some companies experienced financial headwinds.

In April, Chinese electric aircraft developer **EHang** received its production certificate from the **Civil Aviation Administration of China** for its **EH216-S**, a remotely supervised electric vertical takeoff and landing aircraft that seats two passengers. The EH216-S received type certification last year, making EHang the first advanced air mobility company to produce and sell an eVTOL with a standard category airworthiness certificate. The company delivered tens of aircraft to operators in China and claimed a positive, adjusted net profit for the second quarter of 2024. While lack of recognition of EHang's certifications outside of China is a barrier to exports, the company conducted international demonstrations throughout the year, including in the United Arab Emirates and Costa Rica.

The **U.S. small drone industry** took a significant step toward scalable commercial operations with **FAA** approving the first **beyond-visual-line-of-sight commercial deliveries** by multiple operators in the same airspace. This allowed **Zipline** and **Wing**, both of California, to conduct drone deliveries flying below 400 feet (122 meters) in the Dallas/Fort Worth area, relying on a Unmanned Aircraft System Traffic Management system to deconflict their flight plans. FAA also continued to work toward releasing a **notice of proposed rulemaking** for these operations.

In June, California-based **Joby Aviation** anounced the completion of a 840-kilometer flight by a new **hydrogen-fuel-cell-powered air taxi demonstrator**. In May, Virginia-based **Electra** demonstrated takeoff and landing ground rolls shorter than 170 feet (52 meters) with its **Goldfinch**, a hybrid-electric short takeoff and landing, blown-lift demonstrator that was first flown in November 2023. **Joby and Archer Aviation of California** progressed toward **eVTOL type certification** as **FAA** published the final **G-1 certification basis** for each company's **powered-lift aircraft** in the first half of 2024. In June, FAA released for comment a draft advisory circular guiding the certification of other powered-lift aircraft. In October, **FAA** published a special rule for **powered-lift aircraft training and operations.**

In the realm of eVTOL flight tests, **Archer and Vermont-based BETA Technologies** completed **bidirectional transitions** between powered-lift and wing-borne flight with their prototypes. BETA's first full-transition flight with an **ALIA** occurred in April with a pilot on board, while Archer's **Midnight** performed its first full-transition flight in June with a remote pilot.

As part of **U.S. Air Force Agile Flag exercises** in January and August, California-based autonomous aircraft system developers **Xwing and Reliable Robotics** demonstrated fully automated cargo-carrying flights between military bases with their modified Cessna Caravan aircraft.

There were also policy accomplishments related to advanced air mobility. In March, the **American Planning Association** published a 96-page report for state and local planners and policymakers, describing the coming AAM capabilities and requirements and how to integrate this technology into communities and existing transportation systems. In May, U.S. President Joe Biden signed the **bipartisan FAA Reauthorization Act** signed into law, enacting a variety of recommendations, directives and incentives to accelerate AAM development and deployment.

The effects of tightening markets were visible on the nascent AAM industry. In July, California-based **Universal Hydrogen**, which last year flew a prototype **hydrogen powertrain** intended for regional aircraft, ceased operations. In June, **Joby** acquired the autonomy division of California-based Xwing. Germany-based eVTOL developer **Volocopter** was reportedly weeks away from running out of capital before raising additional funds in June, and **Lilium**, another German eVTOL developer, in October announced it would file for insolvency. For the industry to continue growing and attracting capital, it is critical for industry leaders to deliver on their plans to begin passenger air taxi service in the coming years. ★

Governments, civilian groups increase push for research and reporting

BY PATRICK DONOVAN

The **Unidentified Anomalous Phenomena Integration and Outreach Committee** seeks to improve aviation safety by enhancing scientific knowledge of, and mitigating barriers to, the study of unidentified aerospace phenomena.

A U.S. Navy pilot off the coast of Florida reported this encounter with an unidentified object in 2015. Nine years later, lawmakers in the U.S. and abroad proposed legislation to standardize the processes for reporting such objects and called for increased investigation into the sightings.

U.S. Navy

This year marked a shift in the **unidentified anomalous phenomena, or UAP**, area of study. In addition to raising awareness and reducing the stigma associated with the topic, civil and government groups took several concrete steps toward addressing the potential safety hazard that these objects pose.

In January, U.S. Reps. Robert Garcia (D-CA) and Glenn Grothman (R-WI) introduced the **Safe Airspace for Americans Act**. The bill would compel FAA to "establish procedures and reporting requirements for incidents relating to unidentified anomalous phenomena" and offer legal protection from repercussions against those who report sightings. As of November, the bill was still pending.

In May, some 80 members of the **Japanese parliament** formed a nonpartisan group to advocate for the creation of a government organization to investigate UAP. Led by Yasukazu Hamada, a former Japanese defense minister and current parliamentary affairs leader of the ruling Liberal Democratic Party, the group held its first meeting in early June.

In the **European Union**, parliament member Francisco Guerreiro in March introduced a resolution to "propose guidelines for a common methodology for reporting and analysing UAP sightings" in EU airspace. Later that month, scientists, pilots and members of parliament gathered to discuss how to mitigate potential safety risks from UAP.

In July, U.S. Senate Majority Leader Chuck Schumer (D-NY) and Sen. Mike Rounds (R-SD) reintroduced their **UAP Disclosure Act** as an amendment to the fiscal 2025 **National Defense Authorization Act, or NDAA**. The bill would mandate the collection and public release of all government UAP records within 25 years of their creation, as well as establish a review board to evaluate any instances in which select records should be kept classified for reasons including national security. These provisions ultimately weren't included in the draft that was under consideration in mid-November. However, the fiscal 2024 NDAA had directed the **U.S. National Archives and Records Administration** to establish an **Unidentified Anomalous Phenomena Records Collection**, which the agency completed in February.

In March, the **U.S. Defense Department's All-domain Anomaly Resolution Office**, or AARO, released the first volume of its review of past government investigations into UAP. During a press briefing at the Pentagon, acting director Tim Phillips said the office "found no verifiable evidence that any UAP sighting has represented extraterrestrial activity" or that "any information was illegally or inappropriately withheld from Congress." Phillips also said that AARO has been developing a "deployable surveillance system" of unspecified size. Dubbed **GREMLIN**, this sensor suite would be deployed in locations such as restricted airspace where military aviators have reported UAP sightings.

Also in March, **Canada's Office of the Chief Science Advisor** announced that it plans to produce a UAP report as part of the ongoing Sky Canada project, through which the office aims to improve UAP reporting in Canada.

In November, the **U.S. House Committee on Oversight and Accountability Committee** held a two-hour hearing on UAP, with four former government officials presenting testimony. The hearing led to bipartisan calls for increasing government transparency on the subject and protecting whistleblowers. At the same time, AARO released its **Fiscal Year 2024 Consolidated Annual Report on UAP**. AARO said it received 757 new cases since the last report, many of which remained unresolved. Later that month, AARO testified at a **U.S. Senate Armed Services Committee** hearing on UAP.

In academia, there was an increase in published UAP scientific papers throughout the year. The newly created **Sol Foundation**, a think tank that advised governments on the study of UAP, published five new white papers between March and July. And in June, the **Major Cities Chiefs Association,** a nonprofit for police chiefs of major U.S. cities, published and disseminated a detailed **UAP Briefing Guide** to advise departments on handling UAP-related cases and encounters. ★

Trials and test flights mark progress toward autonomous aircraft operations

BY JAMEY JACOB

The **Uncrewed and Autonomous Systems Integration Committee** represents and serves the broad interests of the uncrewed, autonomous and intelligent robotic systems community, encompassing space, aerial, ground, surface water, underwater and other uncrewed and robotic systems, their components and their wide-ranging applications.

▲ Skydweller Aero in October announced the completion of its first flight campaign in which its solar-powered aircraft flew autonomously. The longest flight from the company's Mississippi facility lasted 22.5 hours.

Skydweller Aero

In the **regional air mobility sector**, the push toward autonomous cargo operations continued. In February, **Reliable Robotics** of California announced **FAA** accepted the testing plan for its autonomous flight technology, which the company flew last December in an unoccupied **Cessna 208B Grand Caravan** supervised by a remote pilot. In August, **Reliable Robotics** and California air taxi developer **Joby Aviation** participated in a **U.S. Air Force Agile Flag exercise**, in which each company controlled a Grand Caravan with their autonomous flight technology to transport cargo between military bases. Joby's technology was developed by **Xwing** of California, whose autonomy division Joby acquired in June.

In the **drone delivery** field, **Wing** and **Zipline,** both of California, received FAA approval in June to fly their drones **beyond visual line of sight** in the Dallas/Fort Worth region of Texas, the first time FAA "has authorized multiple drone operations in the same airspace," according to a press release. The trials focused on operational efficiency, safety and air traffic management integration and aligned with national efforts to enhance **last-mile delivery services** via drones. DroneUp of Virginia received approval for BVLOS flights in January, and in November, **Amazon** announced that it had began BVLOS deliveries in the Phoenix metro area.

NASA continued to play a crucial role in developing autonomous flight technologies for air taxis. In a series of tests starting in January, multiple drones were flown autonomously in complex environments BVLOS, a key requirement for the future of AAM, in which **autonomous air taxis** are expected to operate alongside traditional aircraft.

In April, **Joby** broke ground on its planned large-scale manufacturing facility in Dayton, Ohio. In January, **Horizon Aircraft** of Canada secured orders for its seven-person air taxi, underscoring strong market demand for autonomous air transport solutions. In April, **EHang** of China received a production certificate from the Civil Aviation Administration of China, allowing the company to begin mass producing its **EH216-S** pilotless aircraft. But the news was not all positive: In November, **Lilium**, the Munich air taxi developer, announced it and its subidies filed for insolvency.

From March to September, the **UAS World Meteorological Organization Demonstration Campaign** illustrated the potential of uncrewed aircraft systems to complement traditional weather forecasting tools by providing high-resolution data on atmospheric conditions, especially in hard-to-reach areas. The campaign explored operational feasibility and regulatory frameworks for integrating UAS into global meteorological networks, culminating in an international weeklong exercise in Tulsa, Oklahoma, sponsored by **NASA** and **NOAA**.

In the defense sector, the **Pentagon** in July conducted its most challenging counter-unmanned aerial system demonstration to date. At **Yuma Proving Ground** in Arizona, eight C-UAS aircraft were pitted against swarms of up to 50 drones, including a mix of fast jets, propeller-driven fixed wings and multirotor platforms. A layered defense approach was utilized, combining radars, cameras, jammers and other technologies to detect and neutralize threats.

In October, **Skydweller Aero** completed the first autonomous flight campaign of its solar-powered aircraft, which first flew in April. The unoccupied Skydweller, whose wingspan the company reports as being longer than that of a Boeing 747, took off from **Stennis International Airport** in Mississippi and flew over the Gulf of Mexico.

The **U.S. Defense Department's Joint Counter-UAS University** reached full operational capability, integrating C-UAS training into military exercises and conducing live swarm demonstrations in September. To ensure that warfighters from all branches are prepared to respond to evolving drone threats, the training includes basic and advanced courses designed to synchronize C-UAS efforts across the U.S. military. In Canada, directed energy weapons like lasers were tested in May and June during a sandbox exercise, demonstrating their effectiveness in defeating drones at long range. ★

Contributor: *Devin Jacob*

Olympics pay tribute to first hot air balloon flight, industry events call for preserving space artifacts

BY MICHAEL MACKOWSKI

The **History Committee** works to preserve the record of aerospace advances and recognize their impacts on modern society.

▲ A handful of Siskin IIIA aircraft, built by Armstrong Whitworth, were among the first aircraft flown by the Royal Canadian Air Force, established in April 1924.

BAE Systems

The **Paris Olympic**s put on the year's most spectacular tribute to aviation history. Each night, starting with the July opening ceremony, a hot air balloon rose into the skies, hoisting a 7-meter-diameter cauldron, in a tribute to the **Montgolfier brothers'** 1783 balloon flight. The display allowed millions in Paris and around the world to hear the story of the first lighter-than-air flight by humans.

It was also an eventful year for anniversaries. Among them: April marked 100 years since the establishment of the **Royal Canadian Air Force**, and September marked the 100th anniversary of the **first aerial circumnavigation**, a six-month flight completed by U.S. pilots in four Douglas Air Cruisers.

A number of events were held on the history of space exploration and the preservation of artifacts. In January, the **NASA History Office**, with the **National Academies** and the Smithsonian's **National Air and Space Museum**, hosted a multiday symposium in Washington, D.C., about **NASA's Discovery and New Frontiers programs**. Panelists discussed the history of the programs, "their successes and failures, and their impact on knowledge and the practice of planetary science," according to the event webpage.

In March, **Women in Aviation International** held its annual **Pioneer Hall of Fame** ceremony. Among the inductees was **Katherine Johnson**, the pioneering mathematician whose orbital mechanics calculations for the Apollo moon landings were made famous by the book and movie "Hidden Figures."

In April, **AIAA** and a group of the **Society for the History of Technology** cosponsored an online lecture by **Margaret Weitekamp**, this year's recipient of **AIAA's Gardner-Lasser Aerospace History Literature Award**. Her book, "Space Craze: America's Enduring Fascination with Real and Imagined Spaceflight" drew on the Air and Space Museum's extensive memorabilia collection to provide new insights into U.S. space history.

To mark the 55th anniversary of **Apollo 11**, AIAA and the Air and Space Museum in June hosted the **Outer Space Heritage Summit** at the Udvar-Hazy Center outside Washington, D.C. Discussions included how to document and preserve historically significant human and robotic landing sites, artifacts, spacecraft and other evidence of activity on celestial bodies. In August, the **National Park Service** held a multiday symposium in Houston, "Preserving the Race for Space 2024: From the Earth to the Moon and Beyond," centered on the preservation of space exploration facilities and artifacts. The park service's National Center for Preservation Technology and Training hosted the event, partnering with AIAA, Space Center Houston, Cane River National Heritage Area and NASA.

The year's new exhibitions included **"Home Beyond Earth"** at the **Museum of Flight** in Seattle, which opened in June. The space-station-focused exhibition featured some 50 artifacts and invited visitors to create their ideal life on a space station via digital projections and other interactive elements. From June to September, the **New York Hall of Science** in collaboration with NASA, the Air and Space Museum, Boeing and Evergreen Exhibitions, hosted **"Above and Beyond: The Ultimate Flight Exhibition,"** focusing on innovation and opportunities for careers as engineers, pilots or astronauts. In September, the **MIT Museum** in Cambridge, Massachusetts, opened the American premiere of **"Cosmograph: Speculative Fictions for the New Space Age,"** an exhibition by Rania Ghosn and El Hadi Jazairy.

The NASA History Office issued new books on aviation and space history. Among them was **"A Wartime Necessity: The National Advisory Committee for Aeronautics (NACA) and Other National Aeronautical Research Organizations' Efforts at Innovation During World War II,"** edited by Alex Spencer. The book describes how World War II represented a turning point for government-industry cooperation and the role of applied research and development. This and other books are available as free downloads on https://www.nasa.gov/history/. ★

Contributors: *Matt Bille, Kevin Burns, Jonathan Coopersmith and Deborah Douglas*

Drone deliveries, high-speed aircraft and human spaceflight captivate the public

BY CHI L. MAI AND AMIR S. GOHARDANI

The **Society and Aerospace Technology Outreach Committee** examines the relationship between aerospace and society.

Highlights of this year's intersections of society and aerospace technologies included advancements in drone deliveries to consumers, progress on a supersonic aircraft designed not to startle the public with sonic booms, the conclusion of a simulated crewed Mars mission, fascination with a malfunctioning spacecraft and the first private spacewalk.

In July, **FAA** for the first time authorized **beyond-visual-line-of-sight drone flights** by multiple commercial operators in the same airspace. FAA cleared **Zipline** and Alphabet subsidiary **Wing**, both of California, to deliver packages from Walmart stores in the Dallas/Fort Worth, Texas, area to nearby customers, relying on their **uncrewed aircraft traffic management systems** to share data and flight routes to help keep the drones safely separated. In the future, such technology could help enable routine flights where one remote pilot oversees multiple drones flying beyond the pilot's visual line of sight.

In the supersonic flight regime, **NASA** and **Lockheed Martin** in January publicly unveiled the **X-59** at Lockheed Martin Skunk Works' facility in Palmdale, California. This experimental research aircraft is meant to demonstrate a means of reducing the sharp crack of the sonic booms produced by traveling faster than the speed of sound to a gentler "thump." Features of the X-59 designed for quieter supersonic flight include a long, tapered nose and a top-mounted engine. In Octber, engine-run tests began to verify the performance of X-59's systems under its own engine power. NASA now plans for initial flight tests to commence in early 2025, after which pilots will fly X-59 over several U.S. cities to measure the aircraft's sonic thumps and how the public perceives them. The information could lead to the end of FAA's ban on supersonic flight over land by civil aircraft.

Turning to simulated spaceflight on land, a four-person volunteer crew in July concluded **NASA's first year-long analog mission** of a long-duration stay on Mars. Research scientist Kelly Haston, engineer Ross Brockwell, physician Nathan Jones and microbiologist Anca Selariu lived in a **3D-printed Martian habitat** at **NASA's Johnson Space Center** in Houston. They conducted spacewalks, operated robots, maintained their habitat, exercised, grew crops, gave haircuts and contended with communication delays of up to 44 minutes when contacting mission controllers, friends and family. As NASA prepares to return astronauts to the moon and later send humans to Mars, such analog missions can help the agency refine its plans and determine how the conditions of living in another world affect human health and performance.

As part of NASA's Commercial Crew program, a Boeing **Starliner** capsule in June carried astronauts **Barry "Butch" Wilmore and Suni Williams** to the **International Space Station** for the design's first flight with crew. While en route to ISS, several thrusters malfunctioned. After testing and reviews, NASA decided in August that Wilmore and Williams will remain on orbit until February, when they are to return in a SpaceX **Crew Dragon**. The unoccupied Starliner capsule undocked from ISS in September and landed in White Sands Missile Range in New Mexico.

▼ Jared Isaacman partially exits a SpaceX Crew Dragon capsule, becoming the first private citizen to conduct a stand-up extravehicular activity. During this excursion, Isaacman and SpaceX engineer Sarah Gillis took turns evaluating the mobility of their SpaceX suits, an upgraded version of the design that nearly 50 astronauts have worn during trips to and from the International Space Station.

Polaris Program

In a leap forward for commercial spaceflight, two members of the four-person **Polaris Dawn** crew in September performed the first private spacewalk. At an altitude of about 700 kilometers, the hatch on a SpaceX Crew Dragon capsule was opened, exposing **Jared Isaacman, Scott Poteet, Sarah Gillis and Anna Menon** to the vacuum of space. Isaacman, the billionaire founder of Shift4 who founded the flight, and Gillis, a SpaceX engineer, took turns partially exiting the capsule. During their nearly five days in low-Earth orbit, the crew reached a maximum altitude of 1,400 kilometers, the farthest that humans have traveled from Earth since the Apollo 17 lunar landing in 1972. ★

AIAA Bulletin

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We are frequently asked how to submit articles about section events, member awards, and other special interest items in the AIAA Bulletin. Please contact the staff liaison listed above with Section, Committee, Honors and Awards, Event, or Education information. They will review and forward the information to the AIAA Bulletin Editor.

Calendar

6–10 JANUARY 2025
Orlando, Florida

AIAA SciTech Forum is the premier aerospace R&D event of the year. It's where 6,000+ from 45 countries come to witness breakthrough science, revolutionary technologies, and generation-after-next capabilities that are redefining what is possible in aerospace. By attending, you'll immerse yourself in the topics that matter most to you and leave with fresh ideas and new perspectives.

aiaa.org/scitech/registration

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2024			
9–12 Dec	Practical Design Methods for Aircraft and Rotorcraft Flight Control for UAV, AAM, and Civil/ Military Using CONDUIT Course	ONLINE (learning.aiaa.org)	
10–12 Dec*	Space Force Association Spacepower 2024	Orlando, FL	
2025			
6–10 Jan	AIAA SciTech Forum	Orlando, FL	23 May 24
6–10 Jan	26th AIAA International Space Planes and Hypersonic Systems and Technologies Conference	Orlando, FL	23 May 24
8 Jan	2025 AIAA Associate Fellows Induction Ceremony and Dinner	Orlando, FL	
19–23 Jan*	2025 AAS/AIAA Space Flight Mechanics Meeting	Kaua'i, HI (www.space-flight.org)	13 Sep 24
3 Feb–21 Apr	Space Flight Physiology Course	ONLINE (learning.aiaa.org)	
4–25 Feb	Fundamentals of Python for Engineering Programming and Machine Learning Course	ONLINE (learning.aiaa.org)	
6 Feb–10 Apr	Atmospheric and Near-Earth Space Environment Course	ONLINE (learning.aiaa.org)	
11–13 Feb	Understanding Space: An Introduction to Astronautics & Space Systems Engineering Course	ONLINE (learning.aiaa.org)	
11–20 Feb	Business Development for Aerospace Professionals Course	ONLINE (learning.aiaa.org)	
12 Feb–16 Apr	Engineering and Operations for Planetary Field Geology Course	ONLINE (learning.aiaa.org)	
18 Feb–13 Mar	Test Foundations for Flight Test Course	ONLINE (learning.aiaa.org)	

For more information on meetings listed below, visit our website at aiaa.org/events or call 800.639.AIAA or 703.264.7500 (outside U.S.).

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2025			
24 Feb–5 Mar	Technical Writing Essentials for Engineering Course	ONLINE (learning.aiaa.org)	
25 Feb–27 Mar	Electric VTOL Aircraft Design: Theory and Practice Course	ONLINE (learning.aiaa.org)	
26–27 Feb	ASCENDxTexas	Houston, TX	
1–8 Mar*	IEEE Aerospace Conference	Big Sky, MT (www.ieee.org)	1 Jul 24
4–20 Mar	Wind Tunnel Testing for Aircraft Development Course	ONLINE (learning.aiaa.org)	
5–17 Mar	Cislunar Exploration: Challenges and Opportunities Course	ONLINE (learning.aiaa.org)	
10 Mar–16 Apr	Design of Space Launch Vehicles Course	ONLINE (learning.aiaa.org)	
20–21 Mar	AIAA Region I Student Conference	Montréal, Quebec, Canada	10 Jan 25
22–23 Mar	AIAA Region VI Student Conference	Irvine, CA	2 Feb 25
28–29 Mar	AIAA Region IV Student Conference	Dallas, TX	31 Jan 25
3–4 Apr	AIAA Region II Student Conference	Greensboro, NC	3 Feb 25
3–4 Apr	AIAA Region V Student Conference	Minneapolis, MN	31 Jan 25
4–5 Apr	AIAA Region III Student Conference	Cincinnati, OH	8 Feb25
10–13 Apr	29th Design/Build/Fly Competition	Tucson, AZ (aiaa.org/dbf)	
15–18 Apr	AIAA DEFENSE Forum	Laurel, MD	15 Aug 24
29 Apr	2025 AIAA Fellows Induction Ceremony and Dinner	Washington, DC	
30 Apr	2025 AIAA Awards Gala	Washington, DC	
21–25 Jul	AIAA AVIATION Forum	Las Vegas, NV	21 Nov 24
22–24 Jul	ASCEND Powered by AIAA	Las Vegas, NV	21 Nov 24
10–14 Aug*	AAS/AIAA Astrodynamics Specialist Conference	Boston, MA (https://www.space-flight.org)	
14–19 Sep*	International Electric Propulsion Conference	London, UK (www.electricrocket.org)	1 Mar 25
29 Sep–3 Oct*	75th International Astronautical Congress	Sydney, Australia (iac2025.org)	28 Feb 25

Meetings cosponsored by AIAA. Cosponsorship forms can be found at aiaa.org/events-learning/exhibit-sponsorship/co-sponsorship-opportunities.

AIAA Continuing Education offerings

AIAA Announces its Class of 2025 Associate Fellows

AIAA is pleased to announce its newly elected Class of 2025 Associate Fellows. The grade of Associate Fellow recognizes individuals "who have accomplished or been in charge of important engineering or scientific work, or who have done original work of outstanding merit, or who have otherwise made outstanding contributions to the arts, sciences, or technology of aeronautics or astronautics." To be selected as an Associate Fellow an individual must be an AIAA Senior Member in good standing, with at least 12 years of professional experience, and be recommended by three AIAA Associate Fellows.

The Institute will induct the class at the AIAA Associate Fellows Induction Ceremony and Dinner, Wednesday, 8 January, during the 2025 AIAA SciTech Forum, 6–10 January.

Class of 2025 AIAA Associate Fellows

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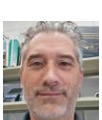

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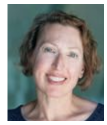

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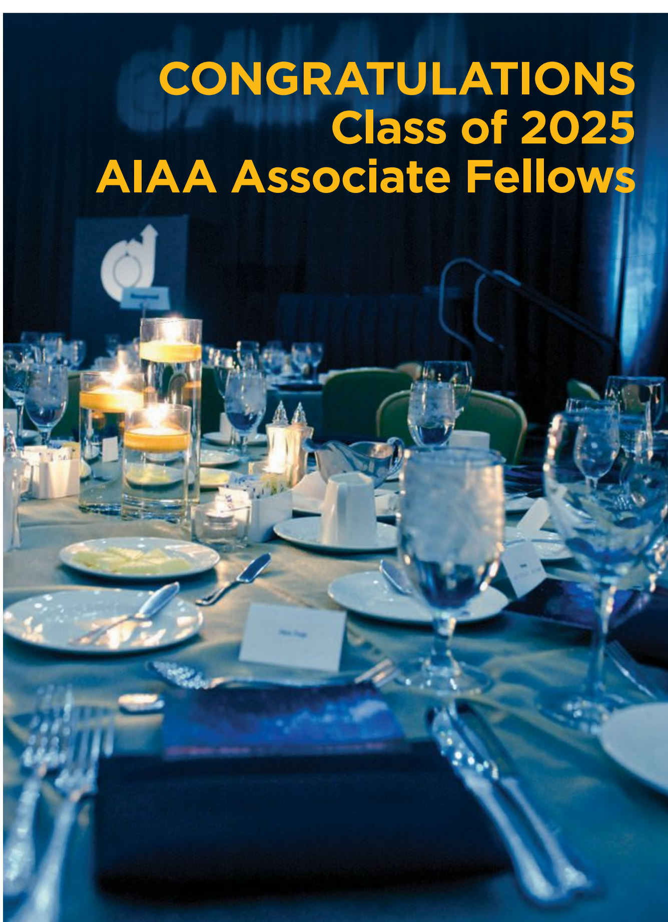
Ann M. Zulkosky
Lockheed Martin Corporation



AIAA Associate Fellows Induction Ceremony and Dinner

Wednesday, 8 January 2025

Hyatt Regency Orlando
Orlando, Florida

The Class of 2025 AIAA Associate Fellows will be officially recognized for their accomplishments in engineering or scientific work, outstanding merit, and contributions to the art, science, or technology of aeronautics or astronautics.

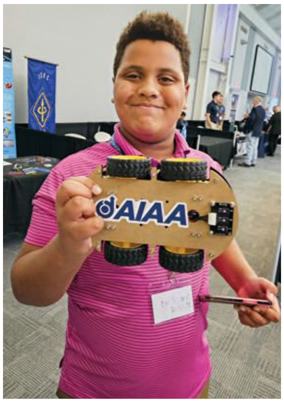
Purchase Tickets at
aiaa.org/SciTech/registration

You do not have to register for AIAA SciTech Forum to register for this event.

AIAA
SHAPING THE FUTURE OF AEROSPACE

MAKING AN IMPACT

3rd SmallSat Education Conference Continues to Grow and Inspire



The 3rd annual SmallSat Education Conference, held 26–27 October at the Astronaut Memorial Foundation's Center for Space Education building at the Kennedy Space Center-Visitor Complex, saw substantial growth this year with 543 registrants from 8 countries. Attendees included educators and students from middle school through postgraduate, all united in their interest and passion for CubeSats, ThinSats, and high-altitude balloons.

The event, whose organizers include the AIAA Cape Canaveral and Palm Beach Sections, featured 36 presentations and 6 workshops. Attendees had the chance to be part of a hands-on soldering opportunity and a workshop focused on preparing students to get their amateur radio license. The keynote speaker, Kenneth Reightler, an astronaut and U.S. Naval Academy professor, shared his experiences piloting multiple shuttle missions, and encouraged the students to get involved with AIAA early in their academic careers. In 2022, organizers donated 16 CubeSat emulators to educators in Peru and this year a contingent of those teachers and students attended the conference to give an update on their success and share their work.

Next year's conference will be held 25–26 October 2025, with a keynote from Norman Fitz-Coy (University of Florida). For more information, visit **www.smallsateducation.org**.

2024 AIAA Aerospace Communications Award Presented in September

Barry Evans (left) was presented with the award by Rabindra (Rob) Singh (right).

Professor Barry G. Evans was recognized with the AIAA Aerospace Communications Award at the 29th Ka and Broadband Space Communications Conference (KaBSC) and the 41st International Communications Satellite Systems Conference (ICSSC) and Colloquium, held 24–27 September in Seattle, WA.

Evans, Professor of Satellite Communications and Head of Satellite Research at the University of Surrey, received the award for inspirational technical leadership in the development of communications satellite concepts, systems, regulations and protocols, and the promotion of satellite communications within the academic community. He has long been recognized as a leading authority on all aspects of advanced satellite communications, and Evans is known as one of the founders of the Satellite Communications faculty at the University of Surrey and was the Founding Director of Surrey Satellite Technology Ltd. His work continues to be highly relevant to the progress of space communications, and much of the current low Earth orbit (LEO) end-to-end networking and spectrum innovations can be linked to work done by Evans.

A Year of Impact: Celebrating Growth and Looking Ahead

Reflecting on the past year, AIAA is excited to see the profound impact of the AIAA Foundation's initiatives. Students are eager to engage with AIAA and recognize the value of our programs—an enthusiasm that is reflected in the tremendous growth across several of our key initiatives. Notably, both the Regional Student Conferences and Design/Build/Fly events have set new participation records in 2024. The Foundation awarded a record-breaking $161,500 in scholarships and graduate awards, marking the highest amount we've ever distributed.

This year, we also welcomed nearly 1,000 new high school members, prompting the creation of a dedicated high school subcommittee to expand the value and benefits we offer to this growing demographic. In addition, we proudly launched a newly updated *Careers in Aerospace* handbook, now including a section dedicated to alternative career paths such as apprenticeships and skills-based training—helping students navigate a broader range of opportunities in aerospace.

Our progress would not be possible without the unwavering support of our donors and volunteers. As we look ahead to 2025 and beyond, we are excited to build on this success and continue to impact even more students. The AIAA Foundation Board has set an ambitious goal to reach 1 million students, and we are confident that we will achieve this milestone in the coming year.

Key program enhancements for 2025 include:

- **Student Conferences:** Expanding eligibility to allow early Ph.D. candidates who are still completing coursework to participate.
- **Design/Build/Fly:** Extending the flyoff event hours, providing more time for flying!
- **Scholarships and Graduate Awards**: Introducing the new $10,000 Mary A. Jackson Scholarship and increasing the Neil Armstrong and Orville & Wilbur Wright graduate awards to $10,000 each.
- **Exploration Generation**: In partnership with the National Science Teaching Association and Estes Education, we are launching the final set of free lesson plans for K-12 educators. This four-year collaboration has already reached over 500,000 students, empowering educators with high-quality lesson plans for elementary, middle, and high school classrooms.

Together, these enhancements will help us continue to inspire and support the next generation of aerospace innovators.

Join Us for the AIAA Foundation Day of Giving on 3 December

The AIAA Foundation is proud to participate in the Day of Giving on 3 December to raise funds to inspire and support the next generation of aerospace professionals, from the classroom to their careers. If you've missed the official Day of Giving, we would still encourage you to donate to the AIAA Foundation (**aiaa.org/foundation**) and help us shape the future of aerospace through our innovative K-12 and university programs—including STEM classroom grants, scholarships, conferences, and hands-on competitions. With your partnership and generosity, we can provide meaningful, long-lasting opportunities that will help students and emerging professionals reach their full potential in the aerospace field.

AIAA NEWS

AIAA Greater Philadelphia Section Hosted November Lecture

The AIAA Greater Philadelphia Section presented a lecture by **Bruce Oestreich**, former Boeing executive and fighter pilot, on 7 November. The talk, billed as "An Evening Well Spent Listening to Tall Tales from a Short Guy," focused on flying the F-16 and F-117 back in the "old days." Oestreich also discussed what it was like supporting and leading development of the V-22 Osprey program. The audience had a chance to ask questions, and the event was followed by a happy hour.

AIAA Phoenix Section Members Attended STEM & Innovation Summit

The AIAA Phoenix Section was represented at the STEM & Innovation Summit at the Arizona Science Center on 22 October. The event, sponsored by the SciTech Institute, featured dozens of exhibits on sharing, networking, and spreading STEM awareness in Arizona. The AIAA information table included Earth, Mars, and moon "gravity jugs" and an air-pumped rocket, plus AIAA handouts on careers in aerospace. The swag giveaways (flying discs, balsa airplanes, and sunglasses) also were popular. AIAA members Michael Mackowski and Scott Fouse spoke with many teachers and students about how AIAA can help them plan their career in aerospace. We were able to network with several STEM nonprofit groups as well. Total attendance for the day was around 500 (mostly educators and high school students).

Obituaries

AIAA Fellow Craig Died in July 2024

Roy R. Craig Jr., professor emeritus of Aerospace Engineering at the University of Texas at Austin who is known for developing the Craig-Bampton Method of component mode synthesis, died on 9 July 2024. He was 90 years old.

Craig received a Civil Engineering undergraduate degree from OU and studied at the University of Birmingham in England on a Fulbright Fellowship. He then earned M.S. and Ph.D. degrees in Theoretical and Applied Mechanics from the University of Illinois at Urbana-Champaign before accepting a position teaching Aerospace Engineering and Engineering Mechanics at the University of Texas at Austin.

For 40 years Craig taught at UT Austin, where he developed 13 different undergraduate courses and 8 different graduate courses and supervised 12 Ph.D. dissertations and 16 M.S. theses. Among his students are an astronaut and numerous leaders in industry and academia. Craig also set up the first computer facilities for his department, made over 80 presentations at technical meetings, published 42 technical reports, and two textbooks.

Craig was the developer of the Craig-Bampton Method, used extensively worldwide to make reduced-order models for analyzing the dynamic response of complex structures. He also pioneered the use of Krylov/Lanczos methods for model reduction and control of flexible structures and contributed to the development of frequency-domain system identification methods. He worked at Boeing in Seattle for two summers and had additional industrial experience with the U.S. Naval Civil Engineering Laboratory, Lockheed Palo Alto Research Laboratory, Exxon Production Research Corp., NASA Johnson Space Center, and IBM.

Craig was an AIAA Fellow as well as a member of numerous associations, including SEM, ASEE, and ASME. He was honored with numerous awards during his career, including the 1996 ASEE/AIAA John Leland Atwood Award, for outstanding contributions in structural dynamics and experimental methods. He also received two citations for his contributions to aerospace structures technology, including a NASA citation for contributions to the U.S. manned spaceflight program. His final project in retirement was publishing an online version of his textbook, *Mechanics of Materials*, and it will continue to reach future engineers and prepare them to help in the world.

Baylor University

Full Professor, Tenure-Track, Aerospace Engineering

The Department of Mechanical Engineering in the **School of Engineering and Computer Science** at **Baylor University** seeks a **Professor of Aerospace Engineering** to start in August 2025.

Complete details and application instructions for this position can be found at: https://apply.interfolio.com/154382

The senior-level position is open to candidates in aerospace engineering with research interests including but not limited to: 1) space exploration and space technologies, 2) commercial space travel, 3) space environments and mechanics, 4) machine learning in aerospace design, 5) advanced simulation and modeling, 6) hypersonics, and 7) sustainable aviation. Candidates with theoretical, computational, and experimental backgrounds are encouraged to apply.

The Department of Mechanical Engineering currently offers a concentration in aerospace engineering within the B.S. in Mechanical Engineering. The candidate selected for the position will be expected to assist in developing and delivering a B.S. in Aerospace Engineering degree program while maintaining a vibrant research program.

The Department of Mechanical Engineering: Baylor's ABET-accredited ME program currently has 19 tenured/tenure-track faculty members including the Kenneth and Celia Carlile Endowed Chair, two clinical faculty members, and four lecturer faculty members. The faculty are internationally recognized in research areas including Biomechanics, Biomedical Sensors, Additive and Advanced Materials, Ceramic and Polymeric Composites, Sustainable Energy and Power Systems, Combustion, Aerodynamics and Thermophysics, and Interfacial Fluid Mechanics.

Baylor University is a private not-for-profit university affiliated with the Baptist General Convention of Texas. As an Affirmative Action/Equal Opportunity employer, Baylor is committed to compliance with all applicable anti-discrimination laws, including those regarding age, race, color, sex, national origin, military service, genetic information, and disability. Baylor's commitment to equal opportunity and respect of others does not undermine the validity and effect of the constitutional and statutory protections for its religious liberty, including, without limitation, the religious organization exemption under Title VII of the Civil Rights Act of 1964, the religious exemption to Title IX of the Education Amendments of 1972, and the Free Exercise Clause of the First Amendment to the United States Constitution, among others. Baylor encourages women, minorities, veterans, and individuals with disabilities to apply.

Assistant (Tenure-Track) or Associate/Full (Tenured) Professor in Mechanical and Aerospace Engineering (MAE)

UCI Samueli School of Engineering | Department of Mechanical and Aerospace Engineering

To support the future of aerospace innovation, the rapidly evolving landscape of aerospace engineering, driven by initiatives such as NASA's Artemis program, the United States Space Force, and the ongoing pursuit of advanced aerial mobility, calls for pioneering innovations in the control of aerospace systems, guidance, and navigation for aerospace applications. Advanced technologies in these areas are crucial for precision in spacecraft and aircraft positioning, course adjustments, and the success of longer-duration missions, and they also play a vital role in enhancing aircraft performance, safety, and efficiency. To address these grand challenges, UCI's Department of Mechanical and Aerospace Engineering seeks exceptional applicants with expertise in the control of aerospace systems, as well as guidance and navigation for space applications. Areas of Interest include:

- Development of advanced Guidance, Navigation, and Control (GNC) systems for space and air applications.
- Advanced control and optimization techniques for spacecraft and aircraft.
- Avionics and robust communication/navigation infrastructure.
- Systems for enhancing aerial mobility.
- Innovations in autonomous systems, including autonomy and robotics for lunar and Martian exploration.

Applicants are expected to have completed a doctorate degree in aerospace engineering, mechanical engineering, or a closely related field, before starting in the position. Moreover, the ideal candidate is expected to develop a vigorous, externally funded research program in the control of aerospace systems and GNC for space applications, make scholarly contributions to the field of flight dynamics and control, have a proven track record of publication and external funding (for senior positions), and express a strong commitment to both undergraduate and graduate teaching. Moreover, they should mentor and guide students with a commitment to inclusivity and diversity and contribute to a dynamic and innovative curriculum and demonstrate leadership and service to the academic community through active involvement in committees, professional organizations, and community outreach. The appointment is anticipated to start July 1, 2025.

For more information about this position and how to apply visit: **https://recruit.ap.uci.edu/JPF09360**

The review process will start on Sunday, Jan 6, 2025.

ABOUT UC IRVINE

The University of California, Irvine is an Equal Opportunity/Affirmative Action Employer advancing inclusive excellence. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability, age, protected veteran status, or other protected categories covered by the UC anti-discrimination policy.

As a University employee, you will be required to comply with all applicable University policies and/or collective bargaining agreements, as may be amended from time to time. Federal, state, or local government directives may impose additional requirements.

Why Starlink must be reined in

BY MORIBA JAH | moriba@utexas.edu

Elon Musk's Starlink internet constellation has charged forward, creating a near monopoly of some 6,500 satellites in low-Earth orbit, with plans underway to add tens of thousands more.

Here is outgoing Federal Communications Commission Chairwoman Jessica Rosenworcel speaking in September with Fedscoop: "We do have one player that's almost two-thirds of the satellites that are in space right now, and has a very high portion of internet traffic. And the way I see it is, our economy doesn't benefit from monopolies," she said, in reference to Starlink.

The U.S. presidential election has put this issue front and center. The ongoing alliance between Musk and President-elect Donald Trump creates a conflict of interest that risks turning Starlink's near monopoly into a full-blown one. Orbital carrying capacity is finite, and once it is consumed by Starlink, that's it. Just like two families can't have separate homes on the exact same land, two satellites can't occupy the same orbital space simultaneously. Starlink is in the process of effectively crowding out competitors at the orbital altitude in which it operates. Musk's relationships with Trump and his allies on Capitol Hill could end any chance of regulating LEO fairly and wisely to ensure sustainability in LEO for all.

The conflict of interest began emerging in May, when Musk created America PAC, a "super PAC" that's permitted to raise unlimited funds for a candidate, provided it does so independently from the campaign. Musk reportedly seeded America PAC with $75 million of his own dollars. Then in November, Trump named Musk and pharmaceutical entrepreneur Vivek Ramaswamy to lead an external group to be called the Department of Government Efficiency that would "slash excess regulations" with advice from "outside the Government," Trump said in a statement on X. He also referenced the department's acronym, "DOGE," and as CNBC reported, the value of the Dogecoin cryptocurrency lauded by Musk in the past shot up.

We all want our government to operate as efficiently as possible, but someone with so much business before regulators and a knack for mixing public and private interests should not be the one to do it. What's at stake? Everything from who controls space and vital communications services on the ground to how U.S. taxpayer dollars are spent.

Here's what we know so far:

Musk turned off Starlink in the midst of a 2022 Ukrainian military operation against its Russian occupiers. No single person or entity should have so much power.

As for tax dollars, Republican Rep. James Comer of Kentucky announced in October that the House Committee on Oversight and Accountability is investigating FCC's decision to stand by a 2022 deci-

Moriba Jah is an astrodynamicist, space environmentalist and professor of aerospace engineering and engineering mechanics at the University of Texas at Austin. An AIAA fellow and MacArthur fellow, he's also chief scientist of startup Privateer.


SpaceX

sion to revoke the potential award of $885.5 million in subsidies to SpaceX and Starlink. These dollars would have been provided under the Rural Digital Opportunity Fund program, but when it reviewed the SpaceX application, FCC questioned the constellation's ability to reach the required data speeds and whether the service would be affordable to most rural people.

Indeed, Musk's narrative of Starlink as a savior for rural and underserved areas (see stories.starlink.com) glosses over key facts: The $599 starting price for Starlink equipment, plus subscription fees, puts the cost of access at barely below the gross domestic product per capita of places like Haiti, Sierra Leone, Rwanda, the Amazon Basin and even some rural areas in the United States.

Also, Starlink's data rate is not high enough to deliver internet parity to rural people. For example, in Austin, Texas — where ironically both Musk and I live — fiber delivers customers 1-gigabits-per-second internet service for $70 a month with no equipment costs. That's 10 times faster than Starlink's standard residential service, whose monthly costs are $120.

We are potentially headed for a taxpayer-subsidized takeover of LEO at the expense of competition, regulatory safeguards, the public interest and science.

The Starlink satellites have already increased the risk of collisions and added to the growing space debris crisis. When a Starlink satellite malfunctions, it can become a piece of unpredictable debris in an already congested space environment. The satellites have also become an obstacle to astronomers and others who rely on clear night skies and low radio interference for their work. Scientists have appealed to FCC to curb Starlink's impact on astronomical observations, emphasizing that the sheer number of satellites, with their brightness and constant transmissions, interferes with faint signals from distant stars and galaxies. This interference could erase decades of progress in understanding our universe, limiting the scope of astronomical research and compromising the integrity of scientific discovery.

In the end, Starlink's emerging monopoly presents a fundamental question that each of us must address in our role as informed citizens: Should the promise of space remain open to all, or should it be permitted to become the dominion of the wealthiest few? ★

Aerospace America publishes a rich variety of opinions relevant to the future of aerospace. The views expressed are those of the author(s) and do not necessarily reflect those of our publisher, AIAA.

LOOKING BACK

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN

1924

Dec. 5-21 The ninth International Aero Show takes place in Paris. Only one British aircraft is on display: an Armstrong Whitworth Siskin V single-seater fighter, stripped of its skin to reveal its construction. Along with German and Dutch aircraft, there are numerous French aircraft on display, including a twin-engined CAMS 33 B flying boat and the Farman F.122 Jabiru airliner. **Flight**, Dec. 11, 1924, pp. 766-777; **Jane's All the World's Aircraft for 1925**, p. 146.

Dec. 11 French pilot Adjutant Bonnet beats the world's airspeed record of 430 kph (267 mph) set by A.J. Williams last year in a Curtiss R-6. Bonnet averages 448.170 kph (278.5 mph) on a 3-kilometer course in Istres, France. The engine of his Bernard SIMB V.2 monoplane burns pure benzole. **The Aeroplane**, Jan. 14, 1925, p. 40; **The Aeroplane**, Dec. 17, 1924, p. 590.

Dec. 13 The all-metal Martin NM-1 biplane flies for the first time at the U.S. Naval Aircraft Factory in Philadelphia. Designed and built by Martin for the U.S. Navy to refine methods for constructing metal aircraft, the NM-1 is to be primarily flown on Marine Corps expeditions. The aircraft is powered by a single Packard 1A-1237 water-cooled engine. **United States Naval Aviation 1910-60**, p. 48.

Dec. 14 A Martin MO-1 observation plane is launched via gunpowder catapult from the forward turret of the USS Mississippi battleship at Bremerton, Washington. Following this demonstration, the powder catapult is widely added on battleships and cruisers. **United States Naval Aviation 1910-60**, p. 48.

Dec. 15 U.S. Army aviator Lt. Clyde Finter completes the first successful midflight linking of two aircraft. Flying a Sperry Messenger, Finter connects with a TC-3 training airship via a boom cradle. This presages the U.S. Navy's efforts to carry fighter aircraft for scouting and protection with the forthcoming USS Akron and Macon rigid airships. David Baker, **Flight and Flying: A Chronology**, p. 155.

Dec. 26 Maurice Demblon of the Belgian Army sets a gliding record for this country, remaining in the air for 37 minutes, 7.8 seconds. **The Aeroplane**, Jan. 21, 1925, p. 62.

1949

Dec. 1 Caltech dedicates a hypersonic wind tunnel that can continually generate airflow speeds greater than 10 times the speed of sound at sea level. Funded by the Army Ordnance Corps, the tunnel was designed by Caltech engineer Allen Puckett to accelerate rocket and guided-missile research. The previous highest-speed tunnel could maintain Mach 7 for only a few seconds. **Aviation Week**, Dec. 12, 1949, p. 30; and Dec. 19, 1949, p. 29.

1 **Dec. 2** The U.S. Air Force launches its first Aerobee RTV-A-1 research rocket from Holloman Air Development Center in New Mexico. The rocket reaches a peak altitude of 96 kilometers and stays aloft for 15 minutes, during which time cameras in the nose took film and X-ray photographs. Development of the Aerobee began in 1946, and the Army began launching its variant in 1947. NASA, **Aeronautics and Astronautics 1915-1960**, p. 63.

Dec. 22 North American pilot George Welch completes the inaugural flight of the first F-86D prototype. The latest version of the famous F-86 Sabre, the F-86D or "Sabre Dog" is the first variant equipped with all-weather interception radar, enclosed in a radome on the nose. Powered by a single General Electric J47 turbojet with an afterburner, the fighter can reach 1,225 kph. David Baker, **Flight and Flying: A Chronology**, p.324.

2 **Dec. 29** U.S. Air Force Reserve Lt. Col. Jacqueline Cochran sets two speed records in her North American F-51C at the 500-kilometer course in Desert Center, California. Her speed of 703.38 kph (437.06 mph) sets a Fédération Aéronautique Internationale record for Class C-1 aircraft without payload, and her speed of 703.275 kph (436.995 mph) is a U.S. first. **Chronology of American Aerospace Events**, p. 57.

1974

3 **Dec. 2** The Soviet Union's Soyuz 16 capsule is launched from the Baikonur Cosmodrome, carrying cosmonauts Col. Anatoly Filipchenko and Nikolay Rukavishnikov to orbit for a test of technologies to be utilized during the upcoming Apollo-Soyuz Test Project. The spacecraft is nearly identical to the one that is to fly in July 1925, when an Apollo and Soyuz capsule dock in low-Earth orbit. As part of the preparations, the Soviets share the spacecraft's orbital parameters with NASA so both agencies can track it, as will be done during the 1975 flight. Along with the on-orbit tests, the cosmonauts conducted scientific and technical investigations and photographed sections of Earth. **New York Times**, Dec. 3-8, 1974.

4 **Dec. 3** NASA's Pioneer 11 probe flies past Jupiter, coming within 21,000 kilometers of the surface — three times closer than its twin Pioneer 10 did during its 1973 flyby. Pioneer 11 transmits the first images of Jupiter's polar regions, then heads toward Saturn for a planned flyby in September 1979. **New York Times**, Dec. 1, 1974, p. 1.

Dec. 4 U.S. President Gerald Ford presents George Low, NASA deputy administrator, with the 1974 Rockefeller Public Service Award. Low joined the National Advisory Committee for Aeronautics in 1949 and was transferred to NASA when it was established in 1958. Early in his career, he oversaw the Mercury and Gemini programs and was one of the planners of the Apollo program. After the 1967 Apollo 1 fire that killed three astronauts, Low was named manager of the Apollo Spacecraft Program Office and charged with overseeing safety upgrades to the Apollo spacecraft. **NASA Activities**, Dec. 15, 1974, p. 8.

Dec. 10 The joint NASA-German Helios 1 solar probe is launched, putting it on a trajectory to fly closer to the sun than any other spacecraft. Helios 1 is to investigate the fundamental solar processes and solar-terrestrial relations by studying the solar wind, magnetic and electric fields, cosmic rays and cosmic dust. **New York Times**, Dec. 9, 1974, p. 45.

Dec. 10 NASA's Lewis Research Center in Ohio announces the completion of flight testing of a United Airlines 747 airliner that is to carry instruments to monitor pollution in the upper atmosphere. Plans call for four such aircraft to eventually be flown under NASA's Global Air Sampling Program to measure dust particles and gases at altitudes between 6,000 meters and 12,000 meters to determine atmospheric and weather effects from emissions from jet aircraft and other pollution sources. **Lewis Research Center Release** 74-80.

Dec. 18 The French and West German Symphonie 1 experimental communications satellite is launched on a Thor-Delta rocket from NASA's Kennedy Space Center in Florida. The first communications satellite built by those countries and the first to use three-axis stabilization in a geostationary orbit, Symphonie 1 will rely on bipropellant propulsion to propel it to its operational orbit over the west coast of Africa and for station-keeping throughout its operational lifetime. **NASA Release** 74-316.

Dec. 18-20 An experimental communications linkup is established between the Mission Control Center at NASA's Johnson Space Center in Texas and Soviet mission control near Moscow, part of ongoing preparation for the July 1975 Apollo-Soyuz Test Project flight. Flight controllers practiced "procedures for interfacing voice, video, teletype, and telex facsimile between the two control centers," according to a press release. **NASA Johnson Space Center Release** 74-275.

Dec. 23 NASA announces that Lee Scherer, director of Armstrong Flight Research Center in California, will succeed Kurt Debus as director of the Kennedy Space Center in Florida. A retired U.S. Navy captain, Scherer oversaw the Lunar Orbiter Program, whose spacecraft photographed the moon to help NASA determine the Apollo landing sites, and later he directed Apollo Lunar Exploration Office that coordinated astronaut science activities during the Apollo lunar landings. NASA, **Astronautics and Aeronautics, 1974**, p. 217.

Dec. 26 The Soviet Union's Salyut 4 space station is launched from the Baikonur Cosmodrome. In early January, cosmonauts Lt. Col. Akexsey Gubarev and Georgy Grechko launch in their Soyuz 17 capsule to dock with the station, the second such platform the Soviet Union has placed in low-Earth orbit. NASA, **Astronautics and Aeronautics, 1974**, p. 218.

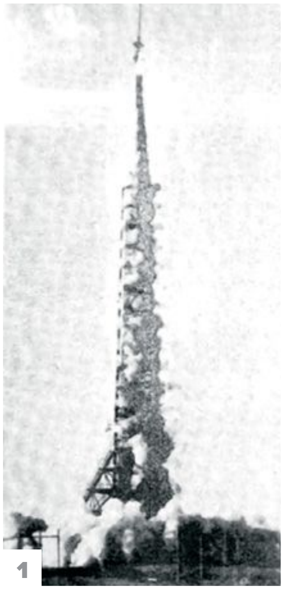
Dec. 30 John Victory, former executive secretary of the National Advisory Committee for Aeronautics, dies in Tucson at 82. Known in the aeronautical industry as "Mr. Aviation," Victory was the first employee of NACA, NASA's predecessor, upon its creation in 1915. When NASA was established in 1958, Victory transferred to the new organization and became the special assistant to the inaugural administrator, T. Keith Glennan, a position he held until his retirement in 1960. **NASA Activities**, February 1975, p. 18.

1999

Dec. 10 An Ariane 5 launches Europe's largest and most ambitious satellite yet, the 4,000-kilogram X-ray Multi Mirror observatory. Called "Europe's Hubble," XXM is the most sensitive X-ray observatory to date, with some 174 mirrors to study gamma-ray bursts, black holes, pulsars and other phenomena not normally visible to standard telescopes. Later renamed XMM-Newton after physicist Isaac Newton, the observatory complements the capabilities of NASA's Chandra observatory launched in July. **Aviation Week**, Dec. 20-27, 1999, pp. 126-127, and April 3, 2000, pp. 58-60.

Dec. 18 NASA's $ 1.3 billion Terra satellite is launched by an Atlas-Centaur, the first launch of an Atlas from Vandenberg Air Force Base in California. Terra, the largest payload of an Atlas to date, is to measure changes to Earth's land masses, oceans and atmosphere from a sun-synchronous orbit. Aviation Week, Jan. 1, 2000, p. 38; **Flight International**, April 25-May 1, 2000, p. 4.

5 **Dec. 21** KOMPSAT-1, the first South Korean satellite, is launched by a U.S. Taurus rocket. The multipurpose spacecraft includes instruments for ocean-scanning, but its main mission is cartography of the Korean peninsula. Korea Research Space Institute developed the satellite with U.S.-based TRW. NASA, **Astronautics and Aeronautics: A Chronology, 1996-2000**, pp. 243-244.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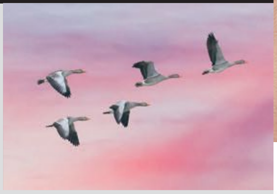
Email us at aeropuzzler@aerospaceamerica.org

Step right up

FROM THE NOVEMBER ISSUE

GET IN FORMATION:

We asked you to describe the phenomena that birds and jets take advantage of when flying in formation. Haithem Taha of the University of California, Irvine reviewed your answers and selected two winning responses.



WINNER Vortex surfing is an aerodynamic phenomenon that birds and jets take advantage of when flying in formation. They use it to ride the spiraling air created by its wing, commonly known as wake vortex (caused by the pressure difference between the top and bottom of the wings). When a bird generates lift, it creates wingtip vortices that create upwash (rising air) and downwash (descending air) around the wingtips. By positioning themselves in V-formation, where each bird lies in the upwash region, trailing birds or jets benefit from this additional lift. This reduces their own induced drag while avoiding downwash areas, conserving energy for long-distance migrations. Similarly, jets in V-formation use vortex surfing by maintaining a precise position relative to the lead aircraft's vortices, which increases its fuel efficiency.

Madhusudan Pun, AIAA student member
Lalitpur, Nepal
Madhusudan studies aerospace engineering at the Institute of Engineering's Pulchowk Campus in Lalitpur.

WINNER Flight occurs because of a balance of forces when the flying vehicle or animal produces enough lift to overcome weight and enough thrust to overcome drag. Lift is generated by higher pressure below the wing than above it. This higher pressure air flows around the wing tip, producing a wing tip vortex that trails behind the vehicle or animal. For commercial aircraft, this represents an energy loss and increased drag, which is why they have winglets. While wing tip vortices are disadvantageous for aircraft and for birds flying solo, they're advantageous for birds flying in formation and save them energy while migrating. The lead bird in the formation bears the full burden of breaking the wind, while the birds behind benefit from the upwash created by the wing tip vortices. The trailing birds synchronize their wing beats and can experience up to 30% energy savings. Birds alternate flying point so that no single member of the flock is overburdened.

Taylor Swanson, AIAA lifetime member
Tullahoma, Tennessee, USA
Taylor is an aerospace engineer at the Arnold Engineering Development Complex.

Q: You're playing a game that requires you to turn over five playing cards, each with a different phrase on it. You must turn back over any card(s) bearing unrelated phrases, and craft a sentence that shows the relationship among the remaining phrases. Your cards say: "The horn of a passing train." "Spectroscopy." "Reynolds Number." "19th Century Austrian mathematician." "Moving Target Indication." Which cards would you leave face up, and what would your sentence say?

SEND A RESPONSE OF UP TO 250 WORDS that someone in any field could understand to aeropuzzler@aerospaceamerica.org by noon Eastern Dec. 10 for a chance to have it published in the next issue.

Scan to get a head start on the next AeroPuzzler

Johns Hopkins University is seeking nominations for the position of the Director of Johns Hopkins Applied Physics Laboratory

Founded in 1876, Johns Hopkins University created the model for the American research university with the scholarly ambitions, norms, and cultures that still define the academy in the United States. APL provides solutions to national security and scientific challenges with systems engineering and integration, research and development, and analysis. Since their founding in 1942 to aid a country at war, they have focused on practical applications of their research in a wide range of scientific and technological fields. Today, their four main sponsored areas of work include air and missile defense, asymmetric operations, force projection, and space science. Additionally, they continue to honor their enduring commitment to work with and inspire future generations of scientists, engineers, and researchers.

The Director is the chief executive officer of APL, and reports to (and is a member of) the APL's Board of Managers through its Chair, and, as a subsidiary and consolidated entity, is also accountable to the University, through its President and ultimately its Board of Trustees.

The Director works closely with other University leaders and trustees with respect to budgetary and capital approvals, risk management and auditing. The Director leads more than 9,500 staff members and oversees hundreds of specialized research and test facilities. The Director will build upon and expand APL's strong partnership with the University's academic divisions and research organizations, including through joint academic appointments and shared research initiatives.

Organizational Structure
APL's organizational structure breaks down into four sectors—Air and Missile Defense, Asymmetric Operations, Force Projection, and Space Exploration—that are devoted to critical work sponsored by government agencies.

Mission Areas
Johns Hopkins APL's 13 mission areas are organized and equipped to meet unique sponsor and mission needs, providing them with dedicated, on-call engineering, scientific, and analytical expertise.

- Civil Space Flight
- Cyber Operations
- Global Health
- Homeland Defense
- National Security Analysis
- National Security Space
- Precision Strike
- Research and Exploratory Development
- Sea Control
- Space Formulation
- Special Operations
- Strategic Deterrence
- Theater Defense

Duties & Responsibilities
RESULTS:
- Delivers contributions of critical national importance.
- Leads bold visionary approaches in groundbreaking innovation and adoption.
- Communicates APL's capabilities and influences national planning and policy.

STRATEGIC LEADERSHIP:
- Formulates a shared vision, establishes strategic objectives and ensures alignment with enterprise perspectives and goals.
- Maintains an understanding and knowledge of external environments (sponsors, government organizations, competitors, industry) plan and operate and the implications for APL.
- Ability to strategically anticipate, interpret, and shape changes in national, customer, sponsor environments and requirements.
- Develops and leads effective business strategies and optimizes them within public sector policies and budget processes.
- Ability to work collaboratively with academic leadership as a member of the University's Council of Deans.

MANAGEMENT AND EXECUTION:
- Operates with integrity and ethics in all relationships and in carrying out all responsibilities.
- Delivers a healthy balance between a "bottom line" business performance perspective, a wide range of current and potential sponsors, and the university community, while always maintaining a patriotic sense of service to the nation.
- Ability to communicate effectively to stakeholders, sponsors, and staff at all levels in a variety of settings.
- Will establish shared vision, focus on mission, and continue to position APL as an employer of choice for the best and brightest engineering and scientific talent at a time when many attractive opportunities abound for such talent and thus ensures the future success of APL and the nation.

KEY RELATIONSHIPS:
- Builds strategic relationships with stakeholders, sponsors, and customers by understanding their needs, making customer satisfaction a top priority.
- Fosters expansion of relationships across the Johns Hopkins community as JHU continues to emphasize a "One University" approach to cross-university initiatives and lowering the barriers to collaboration.
- Models behaviors expected from others and reflects Laboratory culture and values.
- Inspires individuals and team members to respect differences in other's culture, race, gender, age, background, experience, etc.
- Conveys presence that commands attention, respect and confidence and achieves influence and impact.
- The Director will, as appropriate, seek opportunities for technology translation for the benefit of APL sponsors.

STAFF DEVELOPMENT:
- Fosters the development of leadership, technical talent, and strategic perspective within APL, with special attention to the creation and nurturing of a cadre of rising leaders able to step into top leadership roles at the lab.
- Promotes a transparent, accountable, and inclusive community that is committed to diversity and equity and inclusion throughout all aspects of APL.

Qualifications
DOMAIN EXPERTISE:
- Demonstrated achievement and competence in one or more technical areas relevant to APL, with strength in systems engineering.
- Ability to connect APL's government sponsors with the commercial sector and the APL's leadership to effectively develop technologies.
- Ability to understand key sponsor missions, needs, challenges, constraints, and partnership opportunities, as well as risks.
- Demonstrated track record of collaboration as a foundation to work with JHU colleagues and organizations, as well as third parties, in addressing new and different sponsor needs and requirements.

OTHER REQUIREMENTS:
- Johns Hopkins Applied Physics Laboratory advances science and engineering-based invention and innovation in multiple fields. As an advanced engineering systems organization within a premier research university comprising many thousands of engineers and scientists, including thousands of doctoral-holding staff members, it is expected that the successful candidates will themselves be doctoral-holding. Exceptional candidates who do not hold a doctoral degree but who have demonstrated extraordinary leadership and accomplishment in engineering or scientific organizations may be considered.
- Familiarity with the Department of Defense, the Intelligence Community and/or NASA, along with demonstrated success in developing and maintaining key customer and community relationships are crucial. The ideal candidate would have extensive experience and success directly dealing with relevant federal agencies.
- A demonstrable record of unimpeachable integrity.
- The Director must be a U. S. citizen, having or capable of promptly obtaining a TS/SCI security clearance and other specialized security clearances. Johns Hopkins University is committed to recruiting, supporting, and fostering a diverse community of outstanding faculty, staff, and students.

Are you interested in this role?
To apply for this role, please submit your CV, Resume, and other supporting documents to **jhu-apldirector@odgersberndtson.com**.