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AEROSPACE AMERICA

2023 YEAR-IN-REVIEW

DECEMBER 2023 | A publication of the American Institute of Aeronautics and Astronautics | aerospaceamerica.aiaa.org

AIAA
SHAPING THE FUTURE OF AEROSPACE

The sample return capsule from NASA's OSIRIS-REx spacecraft landed in Utah in September. NASA/Keegan Barber

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The U.S. Air Force Research Laboratory allowed artificial intelligence to control an XQ-58A Valkyrie. U.S. Air Force

PAGES 26, 33, 37, 45, 84

India's Vikram lander touched down near the lunar south pole in August.
Indian Space Research Organisation

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The Year in Review

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

ON THE COVER: Spectators on South Padre Island in Texas watched a SpaceX Starship-Super Heavy rocket lift off in April from the company's facility in nearby Boca Chica. Erik Kuna

STARSHIP'S LAUNCH RECORD
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YEAR IN REVIEW

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AEROSPACE AMERICA

DECEMBER 2023, VOL. 60, NO. 11

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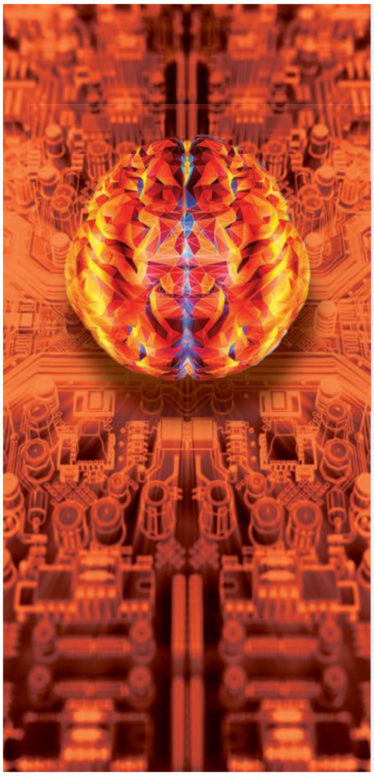
AIAA
SHAPING THE FUTURE OF AEROSPACE



Doubts about AI

Moriba Jah ["Homo machina," October] suggests that we would be wise to begin planning now for a future in which we all morph into cyborgs. Fascinating as his speculations are, we would also be wise to plan for a future in which this does not happen. The dawning of AI is exciting, partly because it forces the realization of how little we understand about the wonderful nature of human intelligence. The mantra among those concerned with autonomous vehicles is beginning to shift from "look how bad human drivers are!" to "look how good human drivers are!"

It is unquestioningly assumed by Jon Kelvey ["The elusive fully autonomous airliner," October] that the arrival of autonomous airliners will be a good thing. Does the young woman on your back cover dream of piloting that Boeing jet? I hope she does and I hope she can, with the best assistance that technology can give her. The purpose of AI (if it has a purpose, if it is not just a flood washing over us) is to enhance the quality of human life. Both of your authors write as though AI were some higher being, toward which we owe a moral duty to concede control.

Philip Roe, AIAA Fellow | Ann Arbor, Michigan | philroe@umich.edu

LET US HEAR FROM YOU

Send letters of no more than 250 words to letters@aerospaceamerica.org. Your letter must refer to a specific article and include your name, address and phone number (Your address and phone number won't be published).

The year we woke up to AI and the need for strong space launch governance

The world's largest rocket taking off was an irresistible choice for the cover of this issue, but not just because of its visual intrigue. Much of NASA's multibillion-dollar Artemis lunar plan hinges on Starship's success, and Elon Musk can't colonize Mars without it. But what's most significant is Starship's forcing function in an age of unprecedented commercial innovation and experimentation by SpaceX and others. Policymakers, regulators and SpaceX now have no choice but to find the right balance between, on one hand, public safety and environmental stewardship and, on the other, technical progress. The progress in the November launch was achieving stage separation. SpaceX celebrated this as a positive step in its "rapid, iterative development approach," but FAA ordered a mishap investigation due to the loss of the two stages. A question is whether the government will be duty-bound to limit how many "mishaps" SpaceX is permitted over public waters.

As impactful as the Starship launches were, that's not the only development for which 2023 will be remembered. Over a span of months, we witnessed artificial intelligence and machine learning "enter our collective consciousness," as NASA's William C. Johnson puts in the Human-Machine Teaming article [page 46]. If you peruse Johnson's piece and others, you'll see how aerospace technologists are beginning to incorporate AI and ML into their work. That's not to say that AIAA members are jumping into this revolution without pointing out the limits of the technology as it exists today. See, for example, the letter to the editor on page 3 reacting to Moriba Jah's column "Homo machina" and our "The elusive fully autonomous airliner" feature by Jon Kelvey, from the October issue.

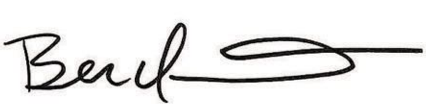
Even Starship has a connection to AI in the following sense: Its creator, Elon Musk, harbors fears deeper than many of us knew over whether the technology will be put to good or ill. Walter Isaacson's biography, "Elon Musk," released in September, recounts how at Musk's birthday party in 2013, Musk and Larry Page of Google fame sparred over whether it would matter if machines rendered people as irrelevant or even made us extinct. "Well, yes, I am pro-human," Musk said. "I [expletive] like humanity, dude."

For Musk and I'm sure many AIAA members, the topics of automation, robotics, AI and ML are no longer just futuristic concerns. They're learning to apply the tech. Isaacson recounts a rough lesson Musk learned about the limits of automation, at least as it existed in 2017. One night at Tesla's Gigafactory for batteries, Musk and his "posse" discovered that humans were still better at some manufacturing tasks, prompting Musk to "de-automate" some processes to meet his heady productivity goal.

Whether it's Starship or production in a Tesla factory, this year reminds us that, for at least awhile longer, the only way to perfect a technology will be to fly it — figuratively or literally. Consider the XQ-58A Valkyrie, an uncrewed military demonstrator. Though a Valkyrie was first flown in 2019, this year one did so under the control of AI algorithms for the first time. Perhaps fighter pilots will be among the first of us to be supplanted by machines. ★

▲ SpaceX's first fully stacked Starship-Super Heavy lifted off in April from Boca Chica, Texas.

Erik Kuna



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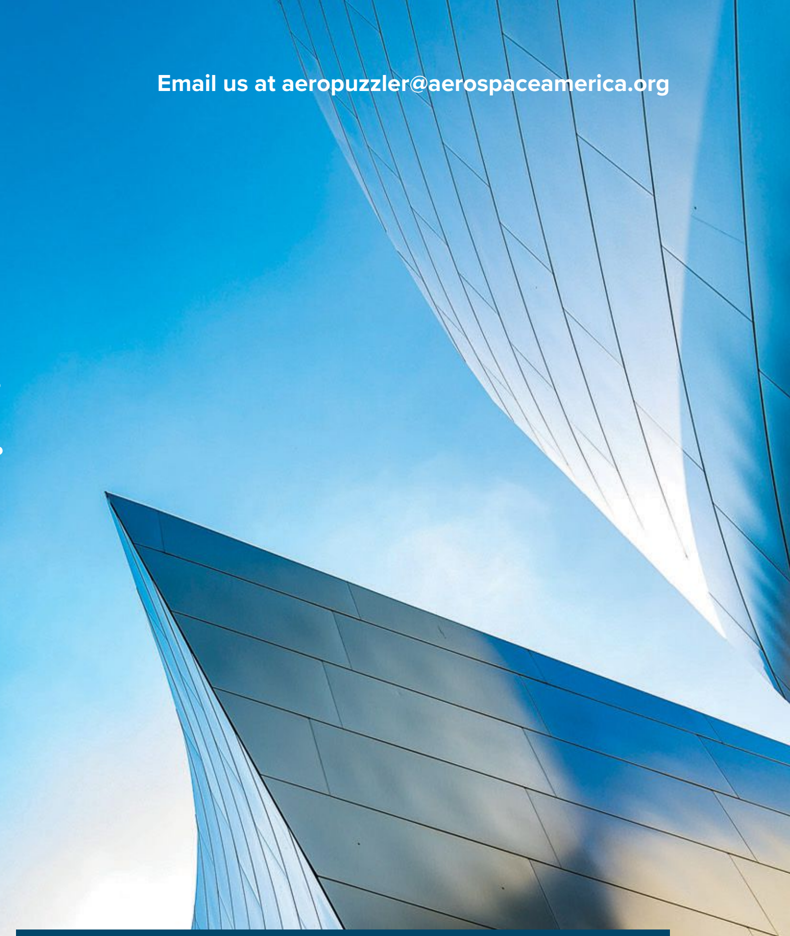

"Nothin' but blue skies," but why?

Q: True or false and why: On a sunny day, the blue sky overhead results from the same principle of molecular absorption that exoplanet researchers rely on to determine the atmospheric composition of planets too dim to be imaged even by the James Webb Space Telescope.

SEND A RESPONSE OF UP TO 250 WORDS that someone in any field could understand to aeropuzzler@aerospaceamerica.org by noon Eastern Dec. 11 for a chance to have it published in the next issue.

Scan to get a head start on the January AeroPuzzler

FROM THE NOVEMBER ISSUE

COAXIAL CONUNDRUM

We asked you whether it's true or false that coaxial helicopter blades are separated by a good distance only so they don't contact each other.

WINNER False. The top and bottom rotor blades of a coaxial helicopter are separated vertically by a good distance for two simple reasons:

1) To reduce aerodynamic interference between the two rotors. When two rotors are close together, the airflow from one rotor can interfere with the airflow from the other rotor, which can reduce efficiency and increase noise.

2) To reduce the risk of blade contact, especially during maneuvers. When a helicopter is maneuvering, the rotor blades can flex and deform. If the blades are too close together, they could contact each other, which could cause a catastrophic failure.

The distance between the two rotors is typically between 10% and 15% of the rotor diameter. This distance is enough to reduce aerodynamic interference and blade contact risk, while still allowing the rotors to interact with each other in a beneficial way. For example, the coaxial rotors on the Russian Kamov Ka-50 helicopter are separated by 15% of the rotor diameter. This separation distance allows the rotors to work together to generate more lift and reduce drag, which improves the helicopter's performance.

Sudarshan Gnanvendan
AIAA student member
Sudarshan.g2021@vitstudent.ac.in

Sudarshan is studying mechanical engineering at Vellore Institute of Technology in India.

Addressing the Industry's Most Critical Topics Through AIAA's Domain Approach

AIAA has been pursuing the Domain approach for the last two years as part of its commitment to solving generational-scale challenges facing aerospace professionals and their organizations. The Institute tapped seasoned industry veterans to serve as Domain Leads for a two-year tenure: Ming Chang for Aeronautics (who sadly passed away in October), Scott Fouse for Aerospace R&D, and Julie Van Kleeck for Space. Each shared their perspective on progress building technology roadmaps, establishing Domain task forces, and collaborating with volunteers from across the AIAA membership and broader community.

AIAA Executive Director Dan Dumbacher reflected on the work of the Domain Leads. "As the inaugural group of AIAA Domain Leads, Ming, Scott, and Julie have been instrumental in bringing this approach from concept to reality. We sincerely thank them and acknowledge their hard work and many contributions to AIAA. We are especially grateful for their visionary leadership as they shape the future of aerospace."

Looking back to when we set out in 2021, we collectively believed that AIAA has a vital mission to serve as the nexus of aerospace technology innovations. The Institute historically has served as the critical collector and disseminator of cutting-edge research and information, addressing challenges for the aerospace industry. The Domain approach was launched to identify the priority issues confronting the aerospace community today and in the future and provide multiyear roadmaps to address them.

Identifying the priority issues across the three Domains was the first order of business. The key topics were informed by inputs collected from members of the AIAA Board of Trustees, Council of Directors, and the Corporate Member Strategic Advisory Committee. The initial topics and priorities were then endorsed by the Domain Leadership Coalition and the Board of Trustees.

We then turned our attention to drafting the roadmaps for each. Roadmaps capture our current understanding of the user, mission, and market needs; capture the unknowns associated with the needs and the technology that enables solutions; and provide insights into current and planned activities that will advance solutions and further developments such as demonstration and experiments.


Scott Fouse


Julie Van Kleeck


Ming Chang

Purpose of the Domain Task Forces

Once armed with endorsed roadmaps, we soon realized that the three of us were not going to be able to effect much change without the collective expertise and contributions of the broader community. We believed the task force model that had been used early on for autonomous vehicle systems and space traffic management was very useful and we applied this model to the key topics.

The primary purpose of the Domain task forces, in our minds, was to increase the AIAA focus on important community needs and to ensure that we balance the technology perspective with user, mission, and market perspectives. That is not to say some of these things were not being done already, but in some cases, there was a need to increase the priority of those perspectives. We also needed to consider the policy perspectives, recognizing that creating policy takes time. The Domain task forces bring together experts with deep footing in the needs of users, missions, and markets to enhance and refine the roadmaps to help accelerate the development and eventual fielding of new capabilities.

Creating the first few Domain task forces was actually a lengthy and a bit bumpy endeavor requiring collaboration across multiple organizations and interested parties. We now believe the Institute

AERONAUTICS KEY TOPICS

- Aviation Decarbonization and Sustainability
- Advanced Air Mobility
- Certification
- Hypersonics and Supersonics

AEROSPACE RESEARCH AND DEVELOPMENT KEY TOPICS

- Transformative Systems Engineering
- Autonomy / Artificial Intelligence / Machine Learning
- Resilient and Assured Systems
- Advanced Manufacturing and Advanced Materials

SPACE KEY TOPICS

- Space Traffic Management / Space Traffic Coordination
- Space Sustainability
- Space Exploration
- Outpacing the Space Threat
- Competitive and Burgeoning Space Economy

has a solid framework for future Domain Leads to use, as the concept continues to evolve over time as more and more AIAA members and our community are engaged. We hope to see an even greater cross-Domain focus in the next generation of Domain task forces.

We appreciated Ming's consistent directive to his Domain task forces, which was deceptively simple: jointly develop an industry landscape assessment and recommendations for AIAA to develop products and engage AIAA members around the key topics. His straightforward message will continue to be part of the Institute's foundation for Domain task forces.

We later realized the opportunity to weave in existing initiatives within the Technical Activities Division (TAD) and the Integration and Outreach Division (IOD) to help advance the work of task forces. In some cases, we have adapted to align and leverage the ongoing work. In other cases, we began engaging directly with TAD and IOD Group Directors and the chairs of Technical Committees (TC) and Integration and Outreach Committees (IOC) in determining what approach is best. This collaboration has further helped crystallize the thinking that Domain task forces should ultimately serve at least one of four fundamental purposes: 1) discovering new insights or knowledge to address a challenge; 2) creating new programs, initiatives, etc., to help solve a challenge; 3) coordinating existing or nascent activities or initiatives of various stakeholders to address a challenge; and 4) enhancing or accelerating existing efforts or initiatives to achieve results sooner.

Updates from the Domain Task Forces

Aeronautics Domain

The **Advanced Air Mobility (AAM) Task Force**, which launched at 2022 AIAA AVIATION Forum and completed its initial work at 2023 AIAA SciTech Forum, provided an opportunity for AIAA to contribute to larger discussions about AAM at the White House's Office of Science and Technology AAM Summit. The task force ultimately identified 11 critical gaps and potential solutions. There are currently three follow-on initiatives plus complementary activities with the Certification Task Force.

The **Certification Task Force**, launched at 2023 AIAA SciTech Forum, will conclude its work at the upcoming 2024 AIAA SciTech Forum. The task force created a focused environment within AIAA for certification experts and enthusiasts to engage with one another in discussion about wide-ranging technical and policy challenges. The principal focus is on addressing challenges related to autonomous AAM hardware and operations and the potential tenfold increase of aircraft in the national airspace.

The **Carbon Emissions and Sustainability Task Force**, which launched in summer 2022 and issued its final report at 2023 AIAA AVIATION Forum, provided a bridge for current member experts in sustainable design to connect with new stakeholders focused on renewable energy and its impacts on airlines and airports. While the initial scope of the task force was on helping commercial aviation meet net zero emissions by 2050, the group soon realized AIAA has the potential and an imperative to consider and address broader climate impacts and ultimately encompass all three domains.

The **High-Speed Flight Task Force**, which will formally launch at the 2024 AIAA SciTech Forum, will draw upon the community's expertise, particularly from members of the Supersonic Integration and Outreach Committee and HyTASP Technical Committee to develop an internationally oriented policy perspective that will promote sustainable, safe, and economical growth of high-speed flights capability.

Aerospace R&D Domain

The **Transformative Systems Engineering Task Force (TSETF)** is working very closely with the Digital Engineering IOC and the Systems Engineering TC to map and promote their current work into specific capabilities that could have significant impact on government acquisition costs and timelines. This includes working together with the DoD to support their efforts in Digital Materiel Management. Because of the potentially broad spectrum of challenges transformative systems engineering might address, the TSETF has elected to focus on autonomous systems of systems.

The TSETF's focus on autonomous systems of systems complements the **Artificial Intelligence (AI)/Machine Learning/Autonomy Task Force** that is just getting started. Their focus is to define a challenge problem in aerospace AI and autonomy that the community can solve. There are many AI challenges in the broader technical community, but they do not address problems confronting aerospace. The task force is looking for a challenge that addresses needs both of scale and verification and validation.

We are currently forming a task force focused on **Advanced Materials and Advanced Manufacturing**. We are assembling a small team to identify a high value direction for this task force in collaboration with the Aerospace Design and Structures Group (ADSG) and the group's Technical Committee leaders.

Space Domain

The **Cislunar Ecosystem Task Force (CETF)** is fulfilling a critical role in the space ecosystem. Space is changing at a very rapid pace. Taking that next step to develop a successful thriving in-space economy comprising the necessary infrastructure and institutions for permanent, sustainable human presence off-world, between low Earth orbit and the lunar surface, is a monumental challenge. We are pleased that the CETF is well positioned as a leading voice. Most recently, the CETF hosted a workshop during 2023 ASCEND to further advance and prioritize its work, and anticipates a strong focus on the economic and adjacent industry aspects of cislunar ecosystem development in the coming year.

The **Space Traffic Coordination Task Force** (STCTF; formerly the Space Traffic Management Task Force) is entering its second phase with a new leader and updated focus. This multidisciplinary group, with representatives from government and commercial space, policymakers, academia, and even the insurance industry, had early success on the public policy front where it provided input on Congressional authorization and budget appropriation for the Office of Space Commerce. Of direct and practical relevance to satellite operators, the STCTF published a widely downloaded white paper, "Orbital Safety Best Practices," in collaboration with industry stakeholders. The task force also supported development of the OSC Traffic Coordination System for Space (TraCSS) by facilitating industry feedback workshops. The STCTF looks ahead to incorporating orbital debris mitigation and remediation into its area of focus, expanding industry acceptance of the best practices paper, and ensuring international perspectives are collected and cooperation ensured.

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Active materials, adaptive structures combine to enhance performance of aerospace systems

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.

This year, multiple efforts across the community addressed **shape-memory materials**. A team at **Arizona State University** made significant progress in developing shape-memory polymer, or SMP, composites with self-sensing and self-healing capabilities. In July, the team demonstrated Joule heating in an SMP glass fiber composite by implementing a conductive indium-tin oxide coating. In October, the team combined the ITO-enhanced glass fiber composites with stress-responsive mechanophores to develop an SMP composite that acted as its own sensor. Developed with **U.S. Office of Naval Research** funding, this novel material will contribute to stronger, safer and more capable aerospace structures.

Regarding shape-memory alloys, students and faculty at **Texas A&M University** continued their collaboration with **NASA's Langley Research Center** in Virginia. In November, the team began construction of a wind tunnel model of a structural component formed from shape-memory alloys designed to significantly reduce noise generated by the slat-wing interface. The planned testing will involve acoustic wind tunnel facilities and a custom-built **scanning beamforming array** to allow researchers to "see" noise reductions from these adaptive structures.

Structural adaptivity without the use of shape-memory materials also showed new promise early in the year. In January, researchers from the **U.S. Army Research Laboratory** in Maryland flight tested a novel **wing-strike alleviation mechanism** that combined classical components with a buckling strip, enabling both wings to sweep back symmetrically when either wing impacted an object. For the flight test, a small drone was flown into fixed poles, resulting in catastrophic failure of unmodified wings. When the wing strike alleviation mechanism was incorporated, both wings rotated to mitigate impact effects and then returned to their original position after clearing the obstacle, enabling recovery and continued flight.

In March, a patent was granted to researchers from **Delft University of Technology** in the Netherlands for a system that passively changed the camber of helicopter blades based on the magnitude of the centrifugal force, which changes with rotor speed. The system allows blades to assume the best possible shape for various flight conditions without requiring additional energy.

In April, the **Army Research Laboratory** supported researchers from **Texas A&M University, the University of Michigan and NextGen Aeronautics** of California in demonstrating a novel automated and multidisciplinary design framework for the first time. Given a set of mission-level requirements — such as mission segments and vehicle speeds — the framework explored the design space of morphing **unoccupied aerial vehicles** with computational fluid dynamics data to quantify the aerodynamic performance, vehicle maneuverability and agility capabilities, design space decomposition to rank adaptivity schemes, and finite element analyses incorporating pressure fields from the CFD to quantify the weight penalties of morphing. The framework was effective in enabling designers to answer two specific questions: "Does morphing provide a significant enhancement in performance?" and "What morphing scheme is most advantageous?"

In October, the **Army Research Laboratory** hosted researchers from **Johns Hopkins University** for wind tunnel testing of a new bistable mechanism for airfoil leading- and trailing-edge morphing. The mechanism consists of rotary elements that rotate a central element by up to 40 degrees. Such a mechanism enabled the deployment and retraction of both leading-edge slats and trailing-edge flaps for changing wing performance across diverse flight conditions. ★

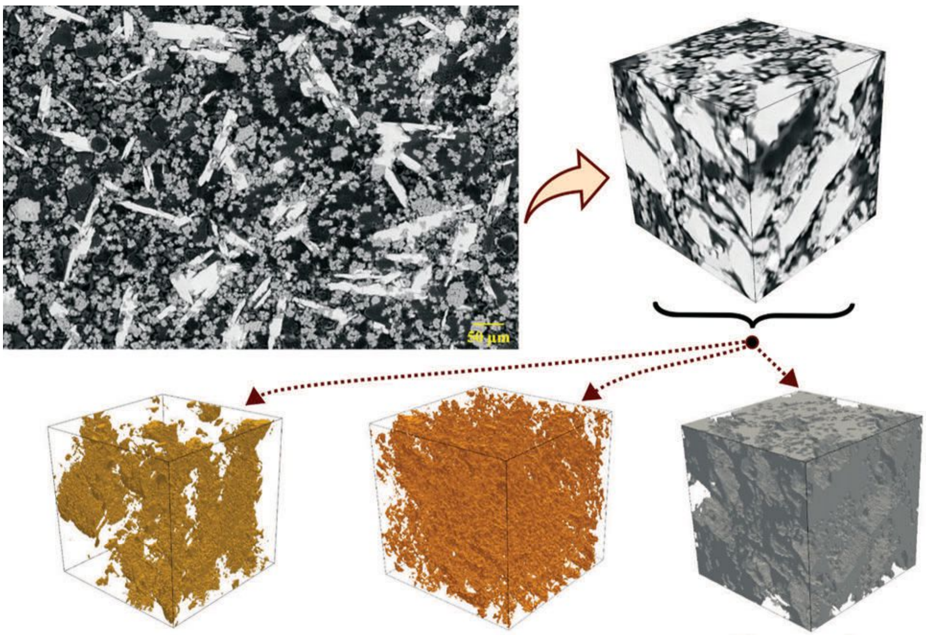
▼ Johns Hopkins University and the U.S. Army Research Laboratory conducted wind tunnel testing of this bistable actuating wing mechanism. Visible in this cross section are the internal rotary components that drive leading-edge and trailing-edge adaption in changing flight conditions.

U.S. Army Research Laboratory and Johns Hopkins University

Computation and AI unlock detailed studies of materials

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.



▲ Penn State University researchers created a machine learning model to analyze and re-create the microstructure of a sample of tricalcium silicate cement (top left) that was mixed on the International Space Station. The cubes on the bottom row are 3D representations of the different components of the cement.

Peter Collins, Vishnu Saseendran, Aleksandra Radlińska and Namiko Yamamoto

When it comes to researching and developing materials for space travel and exploration, **artificial intelligence** is fast becoming not a luxury but a required tool. In January, research teams from the **University of Utah** and **Virginia Commonwealth University** designed a complex carbon nanostructure, via a **machine learning algorithm**, with properties that could match those of desired bulk mechanical properties. This has implications for how machine learning can assist in the exquisite design of materials that are both structural and can survive in deep space. To train their algorithm, the researchers started with a **convolutional neural network** and showed it various configurations of **bundle microstructures**. This taught the algorithm to recognize patterns of material structures suitable for spacecraft construction. They then incorporated this network into a genetic algorithm that now has the ability t o search the bundle microstructure "design space" for configurations that optimally achieve target bulk properties. Finally, they performed three-dimensional **finite element micromechanics analyses** of the nanotube microstructures to yield desirable bulk properties for operation in space.

Another area where computation is required is simulating the hypersonic speeds and adverse weather conditions that vehicles, including military aircraft and future hypersonic craft, will encounter. In May, research teams from **Virginia Commonwealth University** and the **University of Maryland** led by Ibrahim Guven and Christoph Brehm devised a computational approach to study how rain droplets damage vehicle surfaces and degrade **aerothermodynamic performance**. Their method coupled solid mechanics and **computational fluid dynamics** to quantify how the material of a vehicle reacts to striking raindrops, as well as how the shape of droplets changes when they pass through a vehicle's bow shock, depending on the velocity, angle and other conditions. This method, **Peridynamic-CFD Coupling for Adverse Weather Encounters**, could help builders of hypersonic vehicles assess how different materials hold up under extreme thermodynamic states without actually having to be in hypersonic flight.

Elsewhere in materials research, AI helped researchers populate sparse experimental datasets from tiny samples returned from the **International Space Station**. In June, researchers from **Pennsylvania State University** created a **machine learning model** to reconstruct the microstructure of a piece of hydrated **tricalcium silicate cement** that was mixed and cured aboard ISS in 2018. Led by Vishnu Saseendran and Namiko Yamamoto, this **AI-assisted reconstruction** could help material scientists on Earth see firsthand how cement cures in zero gravity, which could influence plans to construct future space habitats and shape future research on properties of space-made materials. This method could also be applied to any experimental samples returning from ISS or the study of other materials, including polycrystalline. When used in conjunction with micromechanics-based tools — such as the **NASA Multiscale Analysis Tool**, as was the case in this experiment — materials scientists could study microstructural characteristics with a much higher resolution than without these in combination. ★

Contributors: *Ibrahim Guven and Vishnu Saseendran*

New software and frameworks for optimizing design and development

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.

This year, several areas in the field of **multidisciplinary design optimization** saw progress both in aeronautical and space applications.

In March, the **Multiscale Multiphysics Design Optimization Laboratory** at the **University of California San Diego** released **ParaLeSTO**. Short for Parallel Level Set Topology Optimization, this code parallelizes OpenLSTO, both of which are based on the level set topology optimization method developed in the lab. It utilizes discrete adjoint sensitivities, allowing automatic differentiation libraries for complex multifunctional design via topology optimization with coupled physics. Multiscale topology optimization was extended to consider electrochemistry and to design the thermal and mechanical load-managing battery system integration for electrical aircraft. In addition, multifidelity modeling allowed researchers to consider material property uncertainties to obtain a robust topology optimization design within a reasonable computational cost.

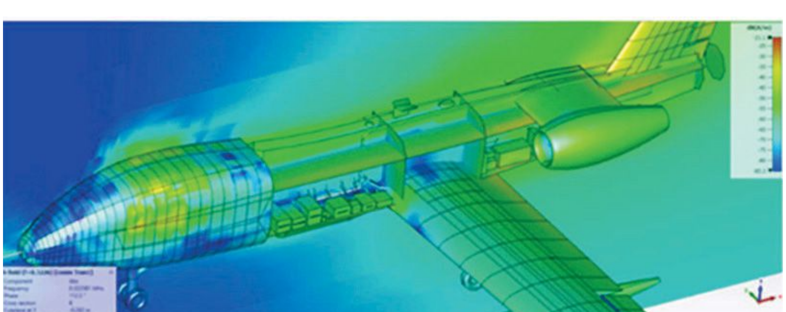
In July, **Brigham Young University's Flight, Optimization, and Wind Laboratory** released major updates to the **ImplicitAD.jl** software package for automating steady and unsteady adjoints leveraging forward- and reverse-mode algorithmic differentiation. Applications include derivatives for a 3D panel code, an unsteady vortex particle method and an unsteady geometrically exact beam analysis, conducted with the **U.S. Department of Energy**. Starting in September, NASA funding supported additional methodology development, aerospace applications and OpenMDAO integration.

At **NASA's Goddard Space Flight Center** in Maryland, a group of researchers in September completed **QUAnT, the Quantification of Uncertainty Analysis Toolkit**. This set of computational tools was designed to efficiently quantify uncertainty as needed to inform and guide the design process of complex, large-scale, multidisciplinary systems throughout their lifecycles. Based on multifidelity modeling and efficient sampling techniques, QUAnT demonstrated two-orders-of-magnitude improvements in computational cost for problems related to **NASA's Mars Sample Return** program.

In Europe, **Airbus** continued its work on digital integration for the **European Union's Horizon 2020** initiative. The company and its partners in February completed the **AGILE 4.0** research project, implementing its digital framework into an Operational Collaborative Environment. Combining model-based systems engineering and MDO in a heavily automated workflow, AGILE 4.0 allows for rapid, complex development with reduced design costs, especially for aeronautical systems. For instance, **Airbus Defence and Space** used the framework to model complex coupled issues including lightning strikes on a medium-altitude, long-endurance drone.

Throughout the year, **Airbus** entered research partnerships on the following projects: The U.K. Aerospace Technology Institute-funded **ONEHeart**, which is studying overall aircraft design and sustainable aviation; the European Union Horizon-funded **Ultra Performance Wing**, or UPWing; and the U.K. government-funded **NextWing**, which looks at the design and manufacturing of the next generation of high-performance transonic wings, with a focus on structural design, materials and manufacturing. The aim is by including high-fidelity and contextual operational effects in the early stages of product design, the companies will develop complementary technology bricks such as semantics and simulation data management and incorporate real-world event simulation. The research intent is to demonstrate probable concept maturity far earlier in the product design process. Total funding for the projects exceeds €120 million ($127 million) over the next four years. ★

***Contributors:** Nathalie Bartoli, Alicia Kim, Martin Muir and Andrew Ning*



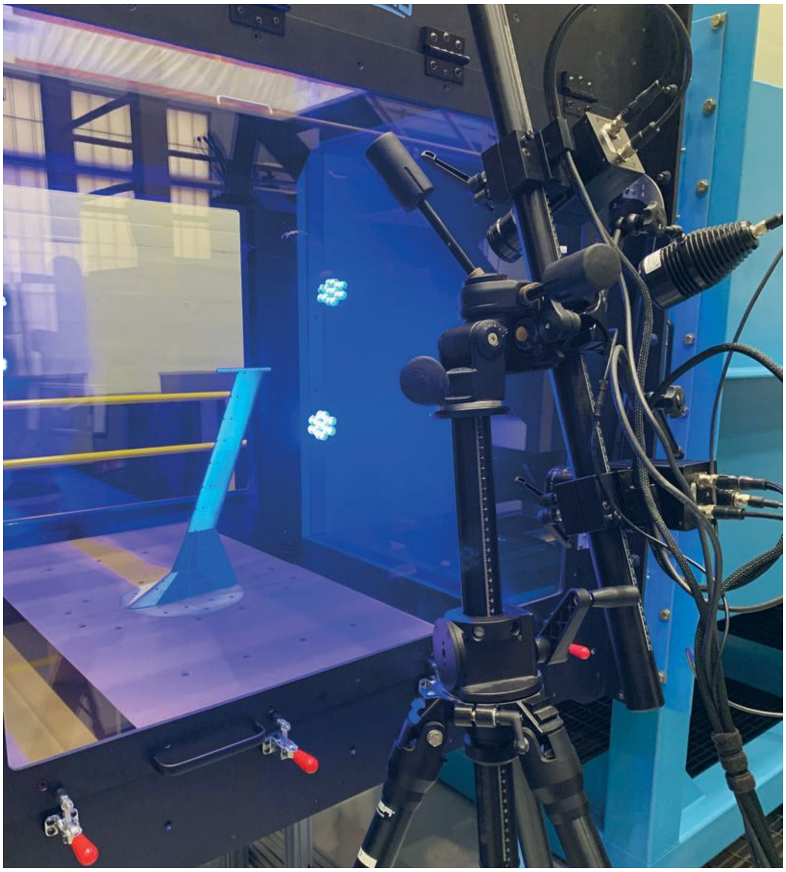
◀ Airbus Defence and Space applied the AGILE 4.0 framework to model issues including lightning strikes on this design for a medium-altitude, long-endurance unoccupied aircraft. Blue represents a low-strength internal electromagnetic field, with green to orange tones representing higher strengths.

Airbus

Rapid aeroelastic testing, metamaterials, and design and analysis headline the year's activities

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

BY DANIEL L. CLARK



▲ Scaled-down models of aircraft components, such as the semi-span wing in this photo, were placed on a rotary table at Wright-Patterson Air Force Base in Ohio to measure flexing under various aerodynamic loads. The researchers tested models comprised of different materials and built via different additive manufacturing processes to quantify repeatability and reduce risk to future test articles.

Air Force Research Laboratory's Aerospace Systems Directorate

In January, the **U.S. Air Force Research Laboratory** conducted a risk reduction test in the **Parker Subsonic Research Facility wind tunnel** at Wright-Patterson Air Force Base in Ohio. The test was part of investigations into rapid vehicle configuration design-to-test **aeroelastic phenomena**, such as flutter. The test was also among a series of firsts at AFRL: the first wind tunnel test with both statically and dynamically aeroelastically scaled models and the first wind tunnel test using both noncontact measurement and optimized additively manufacture models to show rapid-cycle and low-cost configuration measurement.

In January, researchers from **Pennsylvania State University,** the **Argonne National Laboratory** in Illinois and **Florida State University** published their method of estimating the reliability of complex systems at reduced costs in the **Journal of Computational Physics**. Previously, gas turbine blade reliability was estimated via an expensive high-fidelity model. The researchers applied a multifidelity Gaussian process-based approach to show that a combination of low- and high-fidelity models can estimate system reliability more accurately and with up to 50 times reduced computational cost, compared to the high-fidelity model alone.

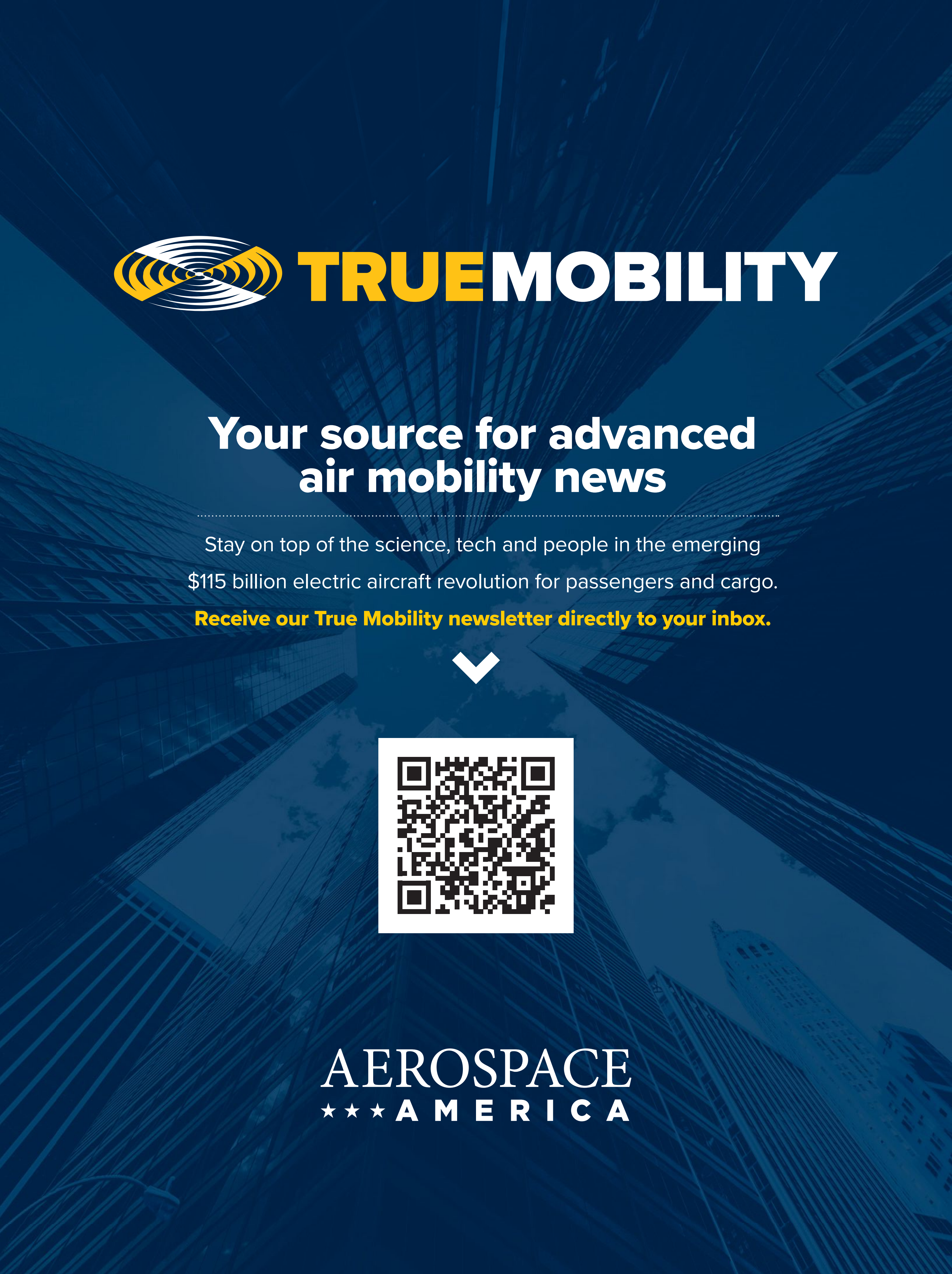
In February and May, researchers from the **University of California, San Diego** introduced two methods to compute risk for structures including riveted silicon carbide composite plates for high-dimensional dependent random inputs (up to 30). Via surrogate models, they estimated the risk of damage to a fiber-reinforced composite laminate 20 times faster than conventional methods.

Also in May, **Northrop Grumman** air vehicle designers demonstrated the trades of analyzing two Air Force-relevant configurations with the **uncertainty quantification, or UQ, method**. The work was conducted under AFRL's Enabling Quantification of Uncertainty in Aerospace Technology Evaluation program. The integration of UQ into multidisciplinary design, analysis and optimization framework for mission effectiveness highlighted the relationship between design decisions, uncertainty and design margin.

In July, a computational materials design team at **Virginia Tech's ASTRO Lab** proposed a methodology to quantify the variations of the structural properties of cellular mechanical metamaterials as a result of manufacturing defects. The uncertainty in the resulting mechanical performance was predicted accurately by a surrogate model trained with physics-based simulation data. The proposed method estimated the uncertainty affecting a combination of multiple structural properties. The propagation of this manufacturing-related uncertainty was mathematically modeled as the variations captured by an N-dimensional material properties space.

In September, researchers from **NASA's Langley Research Center** in Virginia completed Technical Challenge 1 under the agency's **Hypersonic Technology Project**. The System-Level Uncertainty Quantification and Validation challenge spanned six years and had two primary objectives: develop tools and techniques for assessing uncertainty of complex hypersonic systems and develop a workforce versed in UQ practices. Key achievements included development of multiple approaches for efficient UQ, a novel validation metric for mixed uncertainty, initial development of a new UQ tool suite and the application of UQ to multiple complex problems related to hypersonic systems. Members of the challenge team received a NASA group achievement award, and the work has generated interest and engagement from academia and other U.S. government agencies. ★

Contributors: *Pinar Acar, Edwin Forster, Boris Kramer, Alex Pankonien, Ashwin Renganathan, Tom West and Laura White*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Groundbreaking structural dynamics and aeroelastic tests

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.

▲ Researchers from Politecnico di Milano and the University of Washington in February tested this X-DIA model in a wind tunnel in Italy to investigate active flutter suppression.

Sergio Ricci/Politecnico di Milano

In January, researchers at **Sapienza University of Rome** completed the experimental validation of sloshing **nonlinear reduced-order models** for integration into full-scale structural and aeroelastic analysis tools. The combined effects of rotation and vertical tank motion on the dissipative behavior of sloshing were characterized for the first time with Sapienza's closed-loop control environmental testing device.

Also in January, the **Delft University of Technology** in the Netherlands and the **Israel Institute of Technology** conducted the first **parametric flutter margin, or PFM**, wind tunnel test on a highly flexible wing. PFM is a novel method for safe experimental identification of flutter behavior and prediction of flutter margins via a self-contained measuring wind-mounted device called a flutter pod. The method captured the nonlinear evolution of the flutter boundary as a function of angle of attack of a highly flexible high-aspect ratio wing.

In February, researchers tested a pylon-mounted version of the **X-DIA aircraft wind tunnel model** at the **Politecnico di Milano** in Italy. In this FAA-sponsored joint project with the **University of Washington**, the researchers investigated the impact of free play on aeroelastic stability and active flutter suppression. The test configuration with a pylon allowed researchers to accurately control incidence and sideslip angles, which strongly impact limit-cycle oscillations. Due to the elastic pylon, the model shows two flutter mechanisms — symmetric and antisymmetric wing bending and torsion. By actively suppressing the first mechanism, it was possible to identify the second one. Finally, both flutter mechanisms were controlled, and the model was safely tested at speeds beyond the second flutter point.

In March, NASA finalized the data analysis and correlation for the dynamic rollout test and wet dress rehearsal of the **Space Launch System**, which in late 2022 launched an unoccupied **Orion** capsule for the **Artemis I** mission. In general, rolling out to the launchpad produces relatively small structural loads compared with those experienced during launch and ascent, but these repeated loads can progressively cause structural damage or failure. It is not possible to measure rollout loads while the rocket is at the launchpad, so NASA engineers applied **operational modal analysis** techniques to identify the modal characteristics of the rollout and wet dress configurations.

Also in March, AIAA members Peretz Friedmann, George Lesieutre and Daning Huang published a graduate-level textbook on structural dynamics as the 50th volume of the Cambridge Aerospace Series. The book covers fundamental material in structural dynamics augmented by in-depth treatment of damping, rotating systems and periodic systems.

In June, the **Technical University of Berlin** and the **German Aerospace Center's Institute of Aeroelasticity** froze the configuration of a radio-controlled demonstrator named **TU-Flex** to study the coupling among flight mechanics, aeroelasticity and controls for very flexible aircraft. The demonstrator is to have exchangeable wings, permitting tests of different levels of flexibility: a flexible wing with wingtip deflections up to 10% of the wing semi-span, and a very flexible one with wingtip deflections up to 20%, for which nonlinear aeroelastic effects are expected. Construction of the first prototype started in July. Ground vibration and wind tunnel tests are planned for the end of the year, with first flight tests targeted for 2024.

In July, **University of Michigan** researchers validated their new technique for conducting ground vibration tests for very flexible aircraft. By hanging their flexible aircraft model from a 35-meter-tall crane via bungee cords, they created a suspension system with a very low frequency of 0.15 hertz, sufficiently separated from the aircraft's natural frequency of 0.95 hertz, to measure its modal parameters. ★

Contributors: *James Akers, Carlos E.S. Cesnik, Giuliano Coppotelli, Daning Huang, Dexter Johnson, Teresa Kinney, Russel Parks, Sergio Ricci, Flávio Silvestre, Jurij Sodja and Francesco Toffol*

Lighter-weight structures for aircraft and spacecraft continue to proliferate

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

BY EMILY ARNOLD AND CRAIG MERRETT

◀ Mississippi State University researchers tested this composite aircraft strut door, developed under a grant from the U.S. Air Force Research Laboratory. Comprised of carbon fiber composite, the door's stitched sandwich polymer matrix reduces the likelihood of interior cracks separating the layers of composite.

Mississippi State University

In March, an ultra-lightweight and low-power sensor developed by **MIT, Metis Design Corp. and Analog Devices** in Massachusetts was installed on a U.S. Navy destroyer. Comprised of **polymer nanocomposites**, the 10-gram sensor was designed for structural health monitoring. In August, one of the 25-millimeter-long sensors was installed on a **U.S. Air Force F-15**. The Air Force evaluated the sensor's sensitivity to detecting cracks in airframes and found there was a 90% probability that the design would detect cracks less than 0.5 mm. An FAA evaluation of the design for commercial aircraft yielded similar results. Plans call for Analog Devices to develop a smaller version that would weigh about 1 gram and be 12.5 mm long.

In June, researchers at **Oklahoma State University** developed a **nonconformal mesh modeling approach** to determine the curved beam design that would maximize the critical buckling load for aircraft wing panels. The model simulated increasing amounts of material deposited along the base structures of curved stiffening members. The researchers identified an 87% increase in the buckling load with no weight penalty compared to designs using traditional straight stiffeners and uniform plates.

In January, **NASA** selected **Boeing** to build a full-sized transonic truss-braced wing demonstrator, which in June was designated the **X-66A**. Driven by the target of achieving net-zero carbon emissions by 2050, NASA is conducting the **Sustainable Flight Demonstrator** project to develop technologies for next-generation single-aisle aircraft designs, in collaboration with academia and industry. Boeing estimates the truss configuration could reduce fuel consumption up to 30% compared to today's passenger aircraft, when paired with advanced engines. In August, Boeing delivered an MD-90 airframe to its facility in Palmdale, California, where the company will modify the airframe into a truss-braced wing.

In a project funded by the U.S. Air Force Research Laboratory, **Mississippi State University's Aerospace Engineering Department** developed a **composite landing gear strut door** with a stitched sandwich polymer matrix. The composite door is 50% lighter than its titanium counterpart and stitches through the foam layers with optimized parameters, reducing the likelihood of delamination damage, in which interior cracks cause the composite layers to separate.

Using the **Abaqus** software, **University of Michigan** researchers developed a high-fidelity framework to model composite materials. The enhanced semi-discrete damage model tool set consists of a meshing strategy with failure mode separation, a version of the enhanced Schapery theory and a probabilistic modeling strategy. To validate the model, multiple laminates were simulated under a quasi-static tensile load condition. For the given loading conditions, the model captured complex damage progressions and predicted failure loads with reasonable accuracy. With this framework, researchers can conduct simulations via the **Monte Carlo** probability method to represent different virtual specimens. A team is also developing an Abaqus plugin to simulate the curing process to quantify residual stresses and how materials deform after manufacturing.

In March, **University of Michigan** researchers tested a 3D-printed mock-up of a solar array in a vacuum chamber. The tests were funded by **DARPA** under its **Novel Orbital Moon Manufacturing, Materials, and Mass-Efficient Design** program, in which researchers are studying innovative structures that are additively manufactured, assembled and serviced in space to enable the design of very large structures — about 100 meters — that are between 1 and 5 mm thick. Under the grant, the researchers designed a 66-meter hexagonal array with a truss meant to increase structural damping with only minimal loss in structural stiffness and a creased, thin elastic facing sheet that increases the structure's fundamental frequency without substantially increasing the mass. In the vacuum tests, the vibrations of the 1.3-meter-wide mockup matched the fundamental frequencies predicted by numerical models. ★

U.S. Defense Department researchers improve survivability in the air and in space

BY MARK E. ROBESON

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

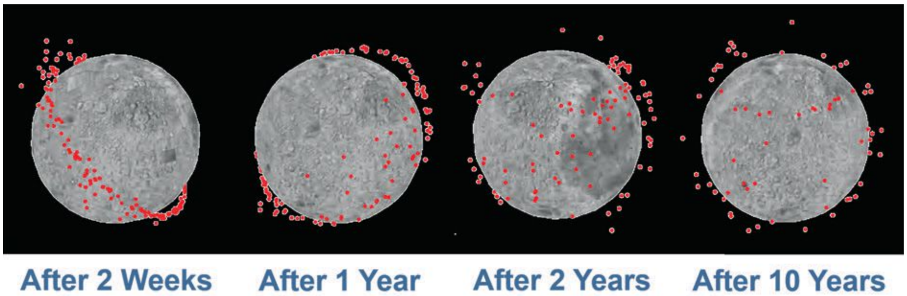
During May and June, the **U.S. Air Force 704th Test Group's Aerospace Survivability and Safety Office** at Wright-Patterson Air Force Base in Ohio conducted **polyalphaolefin oil fire-mitigation** testing. PAO is commonly used in aircraft as coolant, lubricant and hydraulic fluid. With these fluid lines positioned throughout aircraft, PAO fires are large sources of uncertainty in aircraft vulnerability analyses. A fire-mitigating additive was developed that mixes with PAO to reduce the probability of ignition due to ballistic threats. This test program, conducted with the **Joint Aircraft Survivability Program Office**, aimed to quantify the effectiveness of the additive against ballistic fragment impacts, comparing results to baseline ballistic testing of standard PAO. The results contributed to ongoing research into PAO fires by improving the accuracy and reducing the uncertainty of vulnerability assessment models. Plans call for additional testing with fragments in 2024 to further characterize the treated PAO.

From May through July, the **U.S. Air Force Institute of Technology** at Wright-Patterson conducted simulation-based research to analyze the debris risk from **spacecraft breakups** in disposal and reconstitution parking orbits in a variety of cislunar and sun-Earth orbits. With super-computing resources, researchers conducted large-scale **Monte Carlo debris impact simulations** to also investigate debris risks in low lunar orbit. For future tests, plans call for firing a cold gas gun at aerospace-grade aluminum honeycomb panels and additively manufactured components of varying thickness to simulate high-speed impacts of debris fragments. Also next year, researchers are to examine debris risks to the lunar surface, as well multibody planetary systems, including Mars-Deimos-Phobos.

In July, the **U.S. Army Aviation Survivability Integrated Product Team** met at Fort Belvoir in Virginia. Organized by the Aviation Survivability Branch of DEVCOM, the **U.S. Army Combat Capabilities Development Command**, the event brought together an unprecedented group of Defense Department organizations studying aviation survivability. Key participants included the **Joint Aircraft Survivability Program Office**; **U.S. Marine Corps Aviation**; **Naval Air Systems Command** and the **Naval Research Laboratory**; and the **U.S. Army Futures Command Future Vertical Lift Cross-Functional Team**. Participants presented and discussed cutting-edge survivability science, technologies and capabilities, with a focus on sharing essential capabilities for future and current Army aircraft and those for other service branches. Specific topics addressed threat sensing, imaging, modeling and simulation.

Researchers in the **University of Texas Arlington's Advanced Materials and Structures Laboratory** made progress toward breaking through object size limitations of **X-ray computed tomography**, or CT, which makes possible high-resolution **nondestructive inspection**, or NDI, of large aerospace composite structures. X-ray CT has proven to be the only three-dimensional NDI technique with sufficient resolution and objectivity for automated interpretation of inspection results, including manufacturing flaws and damage affecting aircraft survivability. The main challenge is that traditional CT methods and equipment are based on generating X-ray projections all around the inspected object, limiting the methods to high-fidelity inspection of small parts. Simply scaling traditional X-ray CT systems to fit aircraft structure is not the solution, as this makes it nearly impossible to detect critical flaws or damage in composites. The Texas researchers developed **reconstruction algorithms** and software tools for expanding X-ray CT to high-resolution NDI of large structures and paired these with new CT scanning hardware developed by Japanese company **Shimadzu Corp**. The result was a prototype CT NDI system that can conduct high-resolution three-dimensional NDI not possible with conventional methods. From June to November, the prototype inspected large aerospace composite structures with the fidelity required to detect and assess flaws and damage affecting aircraft survivability. ★

Contributors: *Robert Bettinger, Andrew Makeev, Brad Snowden and Carlos Suarez*



◀ Researchers at the U.S. Air Force Institute of Technology in Ohio applied the Monte Carlo probability method to simulate how debris would spread in low lunar orbit in the event of a spacecraft breakup. Multiple simulations were run between May and July to study debris in various orbits.

Air Force Institute of Technology

Accelerating innovation and understanding through model-based systems engineering standardization and artificial intelligence

BY ENANGA D. FALE

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

▲ The U.S. Department of Defense established Task Force Lima in August to study generative artificial intelligence tools and how the department can incorporate them.

Greg Gerken/U.S. Air Force

Innovating the next generation of aerospace systems spanning aviation, space and defense introduces exciting challenges. Today's aerospace systems must balance technology insertions across new and legacy systems or applications alongside creating new aerospace solutions.

To help with this, the **Object Management Group** in February received a draft update of the **Systems Modeling Language, or SysML**, an ANSI standard that provides additional guidance on **model-based systems engineering** standardization and interoperability with other modeling tools. In July, OMG approved **SysML V2.0** for beta specifications, with finalization to a formal standard forecasted for 2024. Preparation for the standard is underway in many organizations, because teams leveraging MBSE can better address aerospace complexity during development activities.

This emerging standard could address a problem identified in the California-based **Aerospace Corp.'s "Model-Based Systems Engineering Cost Study"** released in March and discussed at the **NASA Cost and Schedule Symposium** in May. The study cautioned about the "immature state of MBSE on present programs," the "slow maturation of MBSE" and "budgetary constraints and misuses of MBSE." It also highlighted the need for "standard and common infrastructure, model interoperability and integration and reuse" capability.

In addition to an improved standard, organizations must also proactively explore processes to incorporate the MBSE methodology throughout the engineering lifecycle. Understanding the system dynamics or interdependencies by modeling system behavior or performance enhances an engineer's ability to address the complexity of a system through the entire lifecycle. The **U.S. Defense Department** made this point to the industry in multiple presentations this year, including at the July **International Council of Systems Engineering's International Symposium** in Hawaii, at the **AI4SE and SE4AI Workshop** in September in Virginia (including an industry-requested second online workshop in October) and at the **National Defense Industry Association's conference** in October in Virginia. Defense officials want the industry to proactively seek to drive model connectivity within the modeling ecosystem, using artificial intelligence to innovate solutions across the space, aviation and defense industries. The industry has been advised that MBSE will be incorporated into defense contracts and is viewed by customers as a catalyst for developing more complex and resilient systems.

Another theme struck this year was the need to integrate MBSE with AI, machine learning and data analytics, to create AI/ML-enabled systems or systems engineering tools. In August, the **Department of Defense** established a **generative AI task force** to define a "responsible and strategic" approach to AI implementation. Presenters from the **U.S. Army Combat Capabilities Development Command's Armaments Center** and others at the AI4SE and SE4AI in-person and online workshops emphasized MBSE and the need to evaluate how MBSE should be or is impacted by AI and ML, and how to better manage and design an AI-enabled system, whether it's an aircraft, spacecraft or computer. Among the key goals are to automate visualizations and reports for decision-makers and to build more trust throughout the engineering design process. The workshops challenged engineering leaders to define the critical skills required to couple MBSE and AI development and management of these AI-enabled systems. Industry's standards, technology adoption strategies, task forces and technical forums impress a need for MBSE practitioners to consider how generative AI tools, such as large language models, impact the systems engineering lifecycle.

MBSE and AI can serve as platforms for unlocking the power of systems thinking throughout systems design and increase the ability to manage disruptive and emergent system behaviors. ★

Achieving quieter environments in air and space transport

BY JULIAN WINKLER, 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.

▲ Joby Aviation this year started acoustic and aerodynamic testing of propellers for its planned air taxis in the wind tunnel facility at NASA's Ames Research Center in California, in partnership with the U.S. Air Force and NASA Ames.

Joby Aviation

In January, **NASA** completed tests of a newly developed quiet and efficient spacecraft cabin ventilation fan in the **Acoustical Testing Laboratory at Glenn Research Center** in Ohio. A 72-channel microphone array measured in-duct mode sound power levels. NASA published the fan geometry in its report, "Highlights of Aeroacoustic Tests of a Metal Spacecraft Cabin Ventilation Fan Prototype," to support further research on low-noise fans for long-duration human space missions.

In February, California-based **Joby Aviation** began wind tunnel testing its electric air taxi propellers in the 40-by-80-foot **National Full-Scale Aerodynamic Complex at NASA's Ames Research Center** in California. The performance and acoustic test data of the full-scale propeller system will support Joby's efforts to obtain FAA type certification. In June, Joby received an **FAA Special Airworthiness Certificate** to start flight testing its production prototype.

In March, a **Pratt and Whitney** and **RTX Technology Research Center** team completed aerodynamic drag measurements on various noise optimized novel liner architectures and identified leading concepts for low noise and low fuel burn, under phase three of **FAA's Continuous Lower Energy, Emissions, and Noise, or CLEEN, program**. These high-performance, low-noise acoustic liners are to be installed in commercial engine fan ducts.

In March, NASA announced the **Safe, Low-Noise Operation of UAM in Urban Canyons via Integration of Gust Outcomes and Trim Optimization**, a three-year University Leadership Initiative led by **Boston University**. Researchers will develop prediction tools for community noise of advanced air mobility, AAM, aircraft operating in urban environments.

Also in March, researchers from the **Université de Sherbrooke** in Quebec, Canada, conducted **anechoic wind tunnel tests** on seven small quadrotor drones, creating a database of acoustic measurements in various operating conditions. With the database, Sherbooke researchers tested reduced acoustic models and classified the noise signatures with neural networks. The resulting model can efficiently discriminate the flight mode of the tested drones with a single microphone.

In March, researchers at **NASA's Langley Research Center** in Virginia published the **2022 Proprotor Optimization Data Set** containing performance and acoustic data for four reference-geometry proprotors tested in hover and axial forward flight. The release expands NASA's openly available UAM Noise Working Group database, which industry and research organizations reference for tool validation and technology development.

At the **AIAA Aviation Forum** in San Diego in June, **Whisper Aero** of Tennessee unveiled its **Whisper Jet** aircraft concept in a series of technical papers and a keynote, and displayed a mockup of the vehicle. The design includes **distributed ducted electric propulsion** with large-blade-count fans for low-noise operation. CEO Mark Moore presented acoustic data from wind tunnel and flight testing during a keynote presentation.

From March through August, researchers at **Penn State** conducted an acoustic measurement campaign of a highly instrumented 2.3-meter-diameter reconfigurable multirotor aircraft at **Mid-State Regional Airport** in Philipsburg, Pennsylvania, to inform new noise certification procedures for AAM aircraft with support from **FAA's Aviation Sustainability Center**. Researchers will evaluate measurement and analysis procedures to characterize multirotor aircraft noise, to identify opportunities to reduce noise via the flight control system and to validate Penn State's flight simulation-based noise prediction system for AAM aircraft.

In July, a Dutch appeals court decision cleared the way for a government-mandated reduction of yearly movements at Amsterdam's **Schiphol Airport** from the previous limit of 500,000 to a limit of 452,500 by 2024, motivated by persistent community noise concerns. Dutch airline **KLM** had previously argued against a reduced cap on movements and, in June, offered an alternative plan to reduce noise that included investment in newer, quieter aircraft. ★

Contributors: *Joshua Blake, Sheryl Grace, Eric Greenwood, L. Danielle Koch, Stéphane Moreau, Nicole Pettingill and C. Aaron Reimann*

New measurement capabilities demonstrated for 3D flow properties, high-speed facilities and combustion research

BY THOMAS P. JENKINS

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

In January, researchers at the **Advanced Flow Diagnostics Laboratory at Auburn University** in Alabama demonstrated a novel gridless tomographic reconstruction technique, referred to as **Fluid Neural Radiance Field, or FluidNeRF**, that provides 3D measurements of flow properties or particles in, for example, engine development research or fluid dynamics studies. In May, the researchers compared FluidNeRF to a common reconstruction technique for flow measurements. They found that FluidNeRF increases reconstruction quality, is more robust to noise and shows flexibility to be applied to larger-scale problems.

FluidNeRF uses a machine learning concept in which a 3D volume can be represented as a continuous function of a 3D location. A **feed-forward neural network** approximates the emission density of the 3D scene. The FluidNeRF tomography algorithm operates similarly to traditional methods in which the volume is updated by using the difference between measured and rendered perspectives. The FluidNeRF neural network is updated using the mean squared error between the measured and rendered perspectives. The current implementation of FluidNeRF assumes emission-based, optically thin line-of-sight measurements. The continuous approximation of the volume does not cause an inherent limitation on topology like traditional volume discretization methods. The machine learning structure of the method provides modularity for incorporating various inputs, outputs, accurate ray models and underlying physics. FluidNeRF also provides greater data compression. This technique can be instrumental in improving the modeling and understanding of combustion and high-speed flows.

In June, scientists at **Spectral Energies**, a small business in Ohio, collaborated with the **U.S. Air Force Research Laboratory** in Ohio and the **Arnold Engineering Development Complex** in Tennessee to measure flow velocity via krypton tagging velocimetry, KTV, in a Mach 18 hypersonic wind tunnel in White Oak, Maryland, and picosecond laser electronic excitation tagging, or PLEET, in a Mach 6 Ludwieg tube flow facility at **Wright-Patterson Air Force Base** in Ohio. The scientists used nano- and picosecond high-repetition-rate burst-mode laser systems. With 0.5% krypton as the seeding gas for KTV and nitrogen as the tagging molecule for PLEET, the scientists measured hypersonic flow velocities in the freestream and boundary layers at a rate of 100 kilohertz. Such measurement capability is needed for characterizing high-speed flows while developing hypersonic vehicles.

Collaborators at **Purdue University** in Indiana and **Spectral Energies** continued to push the state-of-the-art in high-speed laser-based imaging and spectroscopy for highly dynamic flow fields. This year's milestones include the first megahertz-rate in situ diesel planar laser-induced fluorescence, which they applied to study the fuel refill process in a rotating detonation engine, 5-megahertz particle image velocimetry in post-detonation blast environments and 20-kHz tomographic 3D volume laser-induced fluorescence of liquid sprays. This work helps the development of advanced propulsion systems for defense applications that may offer increased performance and efficiency.

In September, **Spectral Energies**, in collaboration with the **University of Notre Dame** in Indiana, developed and demonstrated a **plasma-based pressure sensor** on a hypersonic sounding rocket in a wind tunnel at the university. The plasma-based sensor for pressure measurement has a similar form factor to that of a conventional membrane-based sensor and is used similarly. However, the plasma-based sensor has a few advantages. For one, the sensor can withstand adverse environments without needing advanced cooling or other protections. This is due to the fact that the plasma-based sensor uses a controlled plasma contained between two electrodes and not a physical wire or membrane that could rupture. Furthermore, the sensor can automatically reignite if the plasma discharge is lost. Another advantage of the plasma sensor is its megahertz (or higher) sampling speed, which allows it to capture the small time scales that may occur in hypersonic boundary layers or combustion applications. ★

***Contributors:** Justin Jiang and Dustin Kelly*

▼ This plasma-based pressure sensor in September withstood simulated hypersonic flight in a wind tunnel at the University of Notre Dame in Indiana. It was developed by Spectral Energies of Ohio and the University of Notre Dame.
Naibo Jiang/Spectral Energies

Cooperation, perseverance yield progress in aerodynamic prediction reliability

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.

Milestones achieved this year focused on improving core predictive technologies. Midyear, researchers at the **Institute of Aerodynamics and Flow Technology of the German Aerospace Center, DLR**, carried out validation activities to improve the reliability of peak lift predictions for **high-lift aircraft configurations**. Improved reliability reduces the need to overdesign aircraft, leading to more efficient designs. Numerical simulations were executed via the in-house code TAU, and the **low-speed wind tunnel in Braunschweig, Germany**, provided experimental data. The researchers selected the 5.2% scale **High-Lift Common Research Model, or CRM-HL**, as a representative baseline configuration. As part of a DLR-NASA cooperation, **NASA's Langley Research Center** in Virginia provided the wind tunnel model and personnel during almost four months of model preparation and a test campaign. DLR also provided an **ultra-high bypass ratio nacelle** and a **Krüger leading edge system** for the CRM-HL model to investigate a configuration variation. During the test execution, NASA Langley and DLR researchers evaluated preliminary data and shared it between agencies and provided subsets of the data to a larger community of researchers. The tests and simulations fall under the DLR project ADaMant, or Adaptive Data-driven Physical Modeling towards Border of Envelope Applications.

◀ Researchers from NASA's Langley Research Center in Virginia and the German Aerospace Center, DLR, tested this High-Lift Common Research Model aircraft in the low-speed wind tunnel in Braunschweig, Germany. The tunnel data was combined with numerical simulations to validate lift predictions for different aircraft configurations.

DLR's institute of Aerodynamics and Flow Technology

In June, the **University of Cambridge** reported preliminary results of an ongoing study of **aircraft coatings**. Comprised of fibers aligned in the streamwise direction to reduce turbulent skin friction, these coatings were designed to increase the drag-reducing mechanisms present in existing technologies. Preliminary work indicated that these coatings can yield up to 20-25% drag reduction, though these estimates are based on macroscopic models and must be assessed via fully resolved simulations. The resolution required must be fine enough to resolve all the scales of turbulence and the fibers resulting in simulations that are significantly more computationally intensive than conventional simulations. With current algorithms, each simulation would take up to a year to run. Researchers developed new algorithms to execute the same simulations in about a week, so the study of these fibrous coatings can be expedited.

Aerodynamic research at the **University of California, Los Angeles** in May and July focused on the influence of extreme levels of gusts on aircraft wings. The study of **gust-airfoil interactions** involves a large parameter space defined by gust- and flight-characteristic parameters, necessitating a gigantic experimental and computational campaign. The UCLA researchers applied data-driven analysis to show that the aerodynamic flow field data for a large number of computational and experimental cases can be compressed to only three variables using autoencoders while retaining the dynamics of the entire flow field. Their work revealed that the seemingly complex dynamics of violent gust-airfoil interactions are low-rank in nature, offering new avenues for data collection, characterization, modeling, sensing and control of flows around small aircraft that must operate in adverse weather and extreme aerodynamic conditions.

In July, researchers at **Pennsylvania State University** and **Wright State University** posted their **machine-learned turbulence model** on GitHub. This model captures the physics pertaining to pressure gradient forces and yields improved skin-friction predictions for separated flows, both of which are common in aerospace engineering but are difficult to model. The machine-learned model leverages **artificial neural networks** and the high-fidelity data accumulated over the past decade. Furthermore, the researchers preserved the existing calibrations of the baseline Spalart-Allmaras turbulence model, which gives the model the ability to generalize to unseen Reynolds numbers and geometries. This improves the ability to explore new designs and the reliability of tools when applied to unfamiliar geometries and flow conditions. ★

Contributors: *Ricardo Garcia-Mayoral, Ralf Rudnik, Kunihiko (Sam) Taira and Weixing Yuan*

The challenge of access to space

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.

Access to space was once just a dream and is now a reality, but engineering challenges remain. A rocket engine requires exquisitely fine control over an extremely energetic process, which is always a tricky combination. In November, the second fully stacked **Starship-Super Heavy** roared off the pad at Boca Chica, Texas. As planned, the stages separated over the Gulf of Mexico via an updated **hot-staging technique**, in which the Starship engines ignited while still attached to Super Heavy. Shortly after separation, Super Heavy exploded over the gulf, while Starship proceeded on for some minutes before it was also lost. FAA announced that it would oversee a "mishap" investigation of the flight, which came after a truncated first attempt in April that proved the basic soundness of the vehicle and provided valuable data for the updates that culminated in the November test.

Other launch vehicles recorded successes. In November, a reusable **SpaceX Falcon 9 booster** was launched for a record 18th time. A Chinese **Zhuque-2** medium-launch rocket reached orbit on July 12, a first for a methane-powered rocket. Also in July, a **SpaceX Falcon Heavy** launched the **Jupiter 3 satellite**, the most massive communications satellite ever to be sent to geosynchronous orbit.

The **European Space Agency's Jupiter Icy Moons Explorer, or Juice**, spacecraft was launched in April to play a game of cosmic billiards by completing several flybys within the Earth-moon system. Plans call for Juice to make upwards of 30 gravity-assist maneuvers among the moons of **Jupiter** to meet its science objectives. Access to deep space can require extremely high speeds to reach the outer solar system in reasonable time scales, or to decelerate enough from Earth's natural motion to explore the sun and inner planets. Because the energy from a rocket launch is not always enough by itself to complete a deep space mission, astrodynamicists often rely on gravitational flybys of various moons and planets to accelerate interplanetary spacecraft far beyond the initial boost.

Access to the surfaces of moons or planets can also be quite challenging. In April, **ispace's Hakuto-R lunar lander** crashed into the moon at a high speed. The Japan-based company said that the lander likely used up its landing propellant too early during the descent, and attributed the error to the lander's altitude measurement sensors miscalculating the distance due to a software issue, as well as a 2021 decision to change the landing site. Craters and other irregularities of the moon's surface can be difficult to interpret from above, which may have contributed to the loss of the lander. In August, **India** landed its **Vikram lander and Pragyan rover** near the south pole of the moon. The rover later collected scientific measurements of the chemistry and temperature of the lunar surface before entering the lunar night in September.

The ability to change orbits quickly could be viewed as another form of space access within an orbital region of interest. The agility of a spacecraft depends on how much it can accelerate, based on the mass and the thrust level produced by the propulsion system. In February, **SpaceX** launched the first batch of upgraded **Starlink V2 Mini satellites.** SpaceX says the spacecraft are the first to be propelled by **argon-fueled Hall-effect thrusters**, producing higher thrust than previous versions. This should allow for faster deployment into adjacent orbital states to populate constellations.

The technology to provide access to space will improve with lower costs and greater reliability as developers continue to chase the dream of space exploration. ★

▼ FAA directed SpaceX to address a number of anomalies from the April flight of a Starship-Super Heavy before granting the company a modified license to launch a second vehicle in November. Among them, several of the 33 engines on the Super Heavy booster did not ignite or went out as the rocket ascended.

SpaceX

▲ NASA engineers conducted an icing test on this subscale propeller in the Icing Research Tunnel at NASA's Glenn Research Center in Ohio. Ice was shed from the outboard part of the left blade but not on the right.

Andy Broeren/NASA

Machine learning, flight experiments highlight progress in aerospace environments

BY NELSON W. GREEN

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

In May, **UBIQ Aerospace** of Norway announced that it completed testing of its holistic ice protection system, **D•ICE**, consisting of an ice detection sensor, a heated air speed sensor, heated wings and a heated propeller. The system was designed for **small fixed-wing drones** and has several modules that protect all icing-exposed aircraft components, enabling operations and sustained flight in potential and known icing conditions. UBIQ Aerospace flight tested all system components in freezing conditions of minus 13 degrees Celsius with light wind. Tests were performed with a **Maritime Robotics PX-31 Falk** in collaboration with a defense project for the **Norwegian Armed Forces** and the **Norwegian Defense Research Establishment**.

In March, **NASA** completed an icing wind tunnel test campaign with a subscale propeller for **urban air mobility** applications. In-flight icing is an important safety consideration for UAM vehicles, but there are limited experimental data and analysis tools that can be used to demonstrate safe operation. The test campaign was conducted in the **Icing Research Tunnel at NASA's Glenn Research Center** in Ohio to gather data on three geometrically scaled propellers over a range of icing conditions. Acquired data included 3D scans of ice shapes, high-speed video of ice shedding events and changes to motor power requirements during icing exposure. Researchers will use the test results for the continued development and validation on icing analysis tools for UAM applications. The completion of this test campaign marks the first time that NASA has developed and tested a rotating test article in an icing wind tunnel without proprietary industry hardware, ensuring that all results can be made available to the public.

A team from **NASA** and the **Johns Hopkins University Applied Physics Laboratory** in Maryland reported in a June press release that the **Parker Solar Probe** "has flown close enough to the sun to detect the fine structure of the **solar wind** close to where it is generated at the sun's surface." Most of the space around the sun is filled by these **coronal holes**, which are created when **magnetic field lines** "emerge from the surface without looping back inward, thus forming open field lines that expand outward," the press release reads. Based on the team's analysis, "the coronal holes are like showerheads, with roughly evenly spaced jets emerging from bright spots where magnetic field lines funnel into and out of the surface of the Sun. When oppositely directed magnetic fields pass one another in these funnels, which can be 18,000 miles across, the fields often break and reconnect, slinging charged particles out of the Sun." The Parker Solar Probe orbits the sun with the closest approach distance of about 10 solar radii — the closest any human object has every managed to repeatedly visit.

NASA continues to study changes in the near-Earth space environment. In August, NASA selected four **Space Weather Centers of Excellence** to provide data on current conditions as well as forecasts to give space and ground systems time to prepare for space weather events: the **Space Weather Research and Technology Applications Center of Excellence** at Boston College; **Space Weather Operational Readiness Development Center** at the University of Colorado, Boulder; **Center for All-Clear Solar Energetic Particle Forecast** at the University of Michigan, Ann Arbor; and **Center of Excellence for Advanced Forecasting of Drag for Enhanced, Sustainable, and Conscientious Space Operations** at the University of West Virginia, Morgantown. The Space Weather Centers of Excellence program takes advantage of lessons learned from ongoing and past science centers and promotes synergistic, coordinated efforts to transform space weather capabilities and preparedness. ★

Contributors: *Richard Hann and Paul von Hardenburg*

READ THE APPRECIATION

DALE FERGUSON, DEDICATED RESEARCHER OF THE SPACE ENVIRONMENT AND ITS IMPACT ON SPACECRAFT

First flights, launches and reentries mark an eventful year

BY SOUMYO DUTTA, BRADFORD ROBERTSON AND NICOLAS FEZANS

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

Engineers this year analzyed performance data from last year's **Artemis I** mission, in which an unoccupied NASA Orion capsule traveled around the moon and splashed down in the Pacific Ocean. The analysis was done to validate models and prepare for future Artemis missions, including the **Artemis II** crewed lunar flyby scheduled for November 2024.

In September, **NASA's OSIRIS-REx** spacecraft, built by Lockheed Martin, returned samples from the asteroid Bennu to Earth, making the U.S. the second nation to retrieve asteroid samples. The sample return capsule, landed in Utah using a reentry sequence like that of previous missions, including the Japanese **Hayabusa** missions in 2010 and 2020. Built by Lo NASA's first Earth-return mission since the 2006 **Stardust** mission.

In November, **SpaceX** launched its second **Starship-Super Heavy** rocket from Boca Chica, Texas. The booster and upper stage separated as planned, but shortly after, Super Heavy exploded over the Gulf of Mexico and Starship was lost. During the first attempt, in April, a fully stacked Starship-Super Heavy lifted off and flew under control for 85 seconds before losing thrust vector control and exploding over the Gulf of Mexico. Before the November flight, SpaceX redesigned its launch platform by adding a **water deluge system**.

Several notable first flights occurred this year. The **Boeing-Saab T-7 Red Hawk** made its first flight in June. The T-7 is to replace the **U.S. Air Force's T-38 Talon trainers** and features an updated digital cockpit and software to simulate modern aircraft. In May, The **Comac C919** made its inaugural revenue flight in China, beginning Comac's bid to compete against Western aircraft giants Boeing and Airbus in the single-aisle jet market. The **U.S. Air Force's B-21 Raider** made its first flight in November. The B-21 will be the next-generation U.S. bomber platform, replacing the **B-1** and **B-2**.

As of November, preparations were underway for the first flight of **NASA's X-59** demonstrator in 2024. NASA seeks to demonstrate quiet supersonic flight over land with the X-59.

In January, **Boeing** delivered its final **747**. Between 1967 and 2023, Boeing produced 1,574 of the twin-aisle jetliners, democratizing global air travel for millions of people. In recent years, the **747 freighter** has been a mainstay of cargo airlines. A 747 variant has served as **Air Force One**, and the next-generation **VC-25B** is scheduled for delivery in 2027.

▲ A capsule containing rocks and dust from the asteroid Bennu touched down under parachutes in September. The OSIRIS-REx mission — short for Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer — was NASA's first attempt to sample an asteroid and the agency's first sample return mission since 2006.

NASA/Keegan Barber

Early in the year, the **SENS4ICE consortium** led by the **German Aerospace Center, DLR**, along with 16 partners across Europe, the U.S., Canada and Brazil, conducted two flight test campaigns in the U.S. and France to detect supercooled large droplet, or SLD, icing conditions. With a total of 30 flights and 75 flight hours, validation data in natural liquid water icing and in the rare SLD conditions were collected.

In January, the first phase of the eight-year European **Clean Aviation initiative** started. This program focuses on developing technologies toward climate-neutral aviation using three pillars: hybrid-electric regional aircraft, ultra-efficient short/medium-range aircraft and hydrogen-powered aircraft. The initiative will also investigate capabilities to optimize, assess complete aircraft configurations and develop new means of compliance.

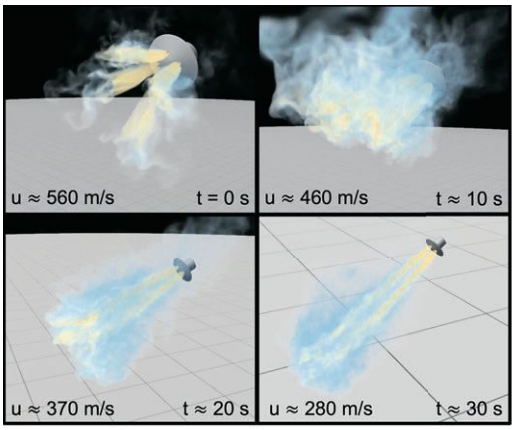
In February, the **X-62 Variable In-flight Simulation Test Aircraft** completed flight testing of its systems and was transitioned to operational use. Flight testing began in December 2022. VISTA provides a platform for **DARPA** and the **U.S. Air Force Research Laboratory** for experimentation of artificial intelligence and machine learning control of a fighter aircraft. The team accomplished constructive AI dogfighting and has demonstrated the use of multiple data links and the ability to quickly modify flight software while taxiing to take off or during flight. ★

***Contributors:** Christopher Cotting and Christopher Karlgaard*

Understanding and controlling fluid behavior in flight-relevant environments

BY PEDRO PAREDES AND UNNIKRISHNAN SASIDHARAN NAIR

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.



This computational fluid dynamics simulation depicts 30 seconds of a human lander descending 6 kilometers through the Martian atmosphere. The "u" indicates velocity in meters per second as the lander fires its retrorockets to orient itself for touchdown.

NASA's Langley Research Center

At the **AIAA Aviation Forum** in June, researchers from the **Air Force Research Laboratory** and **Purdue University** presented results from an experiment involving a laminar, hypersonic shock/boundary-layer interaction, or SBLI. The test utilized an **axisymmetric compression corner model** under low-disturbance Mach-6 flow and demonstrated naturally generated turbulent spots due to a shear-layer instability. That instability amplified over the separation bubble present at the compression corner, due to the SBLI, resulting in breakdown into a **turbulent spot**. This was the first experimental evidence for shear-layer instabilities leading to turbulence under hypersonic quiet flow, which is designed to have freestream disturbance levels like flight environments. Such conditions are challenging to establish since they are typically two orders of magnitude below the freestream noise levels of conventional hypersonic tunnels. Such experiments help improve transition models, allowing engineers to accurately predict heating and controllability of future hypersonic vehicles.

Also at the **Aviation Forum**, researchers from **NASA's Langley Research Center** in Virginia and the **Georgia Institute of Technology** presented high-fidelity large-scale **computational fluid dynamics trajectory simulations** of a human-scale Mars lander descending through the Martian atmosphere with retropropulsion. The CFD solver was coupled with a trajectory analysis package, which provided the necessary control inputs to maintain the desired flight path. Simulations were performed via thousands of graphics processing units on the **Summit supercomputer** at the **U.S. Energy Department's Oak Ridge National Laboratory** in Tennessee. Flight times of approximately 30 seconds were simulated over the course of a few days on the Summit via grids containing several billion elements. Such approaches allow flight controller testing and validation for aerospace vehicles in more realistic flight environments modeled by high-fidelity scale-resolving CFD.

In May, researchers at the **University of Nevada, Reno** pioneered novel techniques for selective adjustment of conservation properties within unsteady fluid flows. With this method, they identified and modified flow structures, altering their kinetic energy while simultaneously preserving the rate of energy dissipation, and vice versa. The approach can stabilize turbulent flows, potentially coaxing them toward steady states and otherwise unstable equilibrium solutions. Through the induction of twist waves within vortical structures, the vorticity and velocity fields present in three-dimensional turbulence can be aligned while leaving the kinetic energy of the flow intact. These techniques could unearth new dynamics in turbulence and enhance aerodynamic performance by disrupting tip vortices.

In August, the **Oak Ridge National Lab** concluded a three-year study of detailed flow field measurements on the upper surface of a wing flap with its partners, the **Air Force Research Laboratory, NASA, the Argonne National Laboratory, Boeing and the University of Notre Dame**. This wing flap was representative of a smooth body, where prediction of flow separation for CFD tools has been a challenge. The results, along with geometry definition, were made available to the broader science and engineering community through **NASA's Turbulence Modeling Resource website**. Such studies can be referenced when developing next-generation turbulence models and evaluation of emerging physics-based methods.

Under an initiative of the **AIAA Reduced-Complexity Modeling and Analysis of Fluids Flows Discussion Group**, a team of researchers from eight institutions compiled a database designed to aid in the conception, training, demonstration, evaluation and comparison of reduced-complexity models for fluid mechanics. In May, a description of the database was published in the **AIAA Journal**, and the database was publicly released. The database contains time-resolved data for six distinct flows spanning a wide range of regimes, including laminar and turbulent, transient and statistically stationary, obtained from experiments and simulations. Broad adoption of this common testbed by the fluid dynamics community would help clarify the distinct capabilities of new and existing reduced-complexity modeling methods. ★

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Increased ground testing and testing capability

BY DENISE A. CHOI

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

This year, the ground test sector saw a substantial increase in testing and testing capability. At the **AIAA Aviation Forum** in June, a team of **NASA, Boeing and the Japan Aerospace Exploration Agency, JAXA,** presented the results of a 2022 sonic boom test conducted with a model of NASA's **X-59** experimental aircraft. In January, members of the **NASA and Boeing High-Lift Common Research Model team** completed a test of the full-span 3.23% scale model of the **CRM-HL** ecosystem reference geometry at Kawasaki Heavy Industries' low-speed aeroacoustics wind tunnel in Gifu, Japan.

After three years of data implementation research at the **11-foot Transonic and the Unitary Plan wind tunnels** at **NASA's Ames Research Center** in California, the **Unsteady Pressure-Sensitive Paint Capability Challenge team** in January released the open-source **uPSP processing software** to increase accuracy of high-speed cameras. The release addressed new techniques for internal and external calibration to store, process, transfer and share uPSP data in near real time.

In February, **Joby Aviation** of California began testing propellers for its electric air taxi at the 40-by-80-foot wind tunnel test section at the **National Full-Scale Aerodynamic Complex** at NASA Ames. Also in February, the **National Research Council of Canada, NRC,** completed the design, build and calibration of a large outdoor rig to simulate in-flight icing conditions for remotely piloted aircraft.

From March to April, the **Technical University of Berlin** conducted a low-speed wind tunnel test of a distributed-propulsion, two-dimensional **airfoil model** in a high-lift configuration at the **German-Dutch Wind Tunnels** in Brunswick, Germany. The test was part of efforts to generate an experimental database for aircraft with **distributed hybrid-electric propulsion**. In September, the university conducted an aeroacoustics test at its DNW-NWB large wind tunnel after tests in 2022 at a lower Reynolds number.

Engineers at **NASA's Langley Research Center** in Virginia completed a new specification, "Fabrication of Additively Manufactured Metallic Parts for Use in Wind Tunnels," filling a gap left by existing standards.

In May, the **National Full-Scale Aerodynamic Complex** at NASA Ames completed a **hover validation and acoustic baseline test** at its 80-by-120-foot wind tunnel test section, the culmination of a multiyear collaboration between **NASA**, the **U.S. Army** and the **AIAA Rotorcraft Hover Performance Working Group**. Advanced optical imaging techniques provided researchers with the most comprehensive data to date to characterize performance of a hovering rotor system.

▲This model of NASA's X-59 experimental aircraft was tested in a 1-meter section of the Japan Aerospace Exploration Agency's supersonic wind tunnel in 2022. The agency and its partners presented the results at AIAA's Aviation Forum in June.
Japan Aerospace Exploration Agency

A **self-aligned focusing schlieren system** was installed and tested in April, May and June at the **National Transonic Facility** at NASA Langley, providing much-needed **flow visualization** in a notoriously difficult environment for optical diagnostics.

In July, NRC completed an aeroacoustics test of a ducted-fan model with baseline blades in the 0.9-meter hemi-anechoic wind tunnel. This was followed by a balance calibration for the council's 2-by-3-meter low-speed wind tunnel, with over 3,000 unique loadings and a comprehensive uncertainty analysis of the calibration.

In September, **NASA Ames' Project Red Rover** created and formalized a process for transferring data collected in the Unitary Plan Wind Tunnel test section to the center's **Advanced Supercomputing Division**, leveraging existing NASA high-end computing capabilities to process large data sets in near real time.

The **University of Arizona** in July installed a **transonic test section** in its 15-by-15-inch polysonic wind tunnel. Plans call for making updates to the air storage system and fast-acting valve storage of the university's 15-inch-diameter Mach 5 **Ludwieg tube**, as well as installing a quiet nozzle. ★

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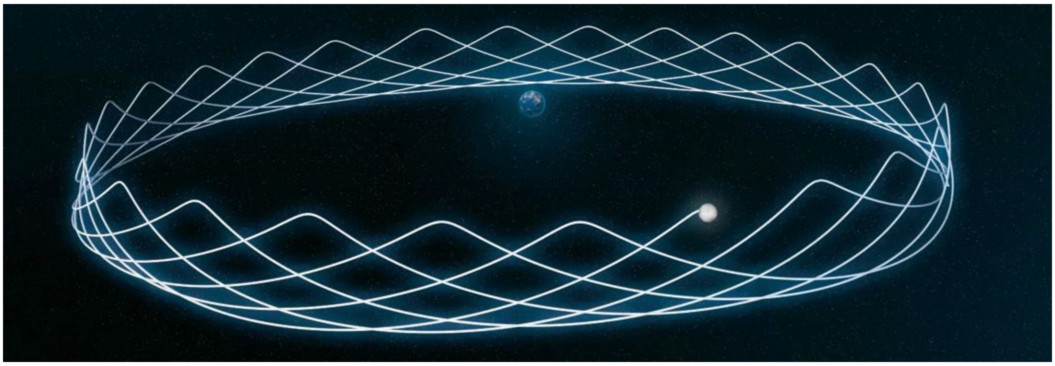
Autonomous systems adapting to uncertain and contested operating conditions

BY JULIE J. PARISH

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



The zigzag lines in this illustration represent the trajectory of the CAPSTONE satellite in its near-rectilinear halo orbit around the moon. From this orbit, the NASA-funded satellite in May began an enhanced mission to demonstrate a technique for deducing position and velocity with the aid of the Lunar Reconnaissance Orbiter, instead of antennas on Earth.

Advanced Space

Across the guidance, navigation and control community, **autonomous and cooperative systems** for complex missions and environments have continued to improve in robustness and resilience.

In January, **NASA** updated post-flight analysis from the **Artemis I** mission, in which a **Space Launch System** rocket launched an unoccupied **Orion** capsule toward lunar orbit in November 2022. Analysis reports indicate that SLS performed nominally, including the new adaptive augmenting control technology.

In November, **SpaceX** launched its second fully stacked **Starship-Super Heavy**. The stages separated as planned over the Gulf of Mexico, but Super Heavy exploded shortly after and Starship was lost, prompting FAA to announce that SpaceX would conduct a "mishap" investigation. The November flight demonstrated the new **electronic thrust control vector system** developed after the truncated first attempt in April, in which communications were lost.

NASA has also made contributions in navigation. In May, the **Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment, or CAPSTONE**, satellite demonstrated cooperative navigation with the **Lunar Reconnaissance Orbiter**. CAPSTONE also flew a **near-rectilinear halo orbit** for over six months, allowing for further study of dynamics and control of nontraditional, fuel-efficient orbits.

In July, NASA announced its **Tipping Point** selections, which included **Psionic** of Virginia. Psionic received the license for **NASA's Navigation Doppler Lidar** The lidar will be integrated in lunar landers under development. In May, Psionic received additional **Phase-3 Small Business Innovation Research funding** from **NASA** and the **U.S. Defense Department** to develop a **high-powered photonic integrated circuit** to shrink the government lidar from 12 kilograms to under 3 kg for a commercial version.

The **European Commission's Directorate-General for Defense Industry and Space's Joint Research Center** released a report in March on its assessment of alternative position, navigation and timing solutions. Per the report, **Locata** of Australia demonstrated the highest positioning accuracy with its network of **LocataLites** ground states. Also exceeding industry benchmarks were Virginia-based **Satelles**, which operates its **Satellite Time and Location service** on low-Earth orbit satellites including the Iridium constellation, and Virginia-based **NextNav's TerraPoiNT**, which uses several sources including TerraPoiNT transmitters. In July, **NextNav** demonstrated its alternative navigation capability on TerraPoiNT using existing **LTE** and **5G** cellular signals in San Jose, California. In May, **Spirent Communications** of the U.K. announced certification of its **SimXona** satellite constellation simulator by California-based **Xona Space Systems**, which is developing the **Pulsar** small-satellite PNT service also envisioned for LEO operation.

There was also a lot of movement in the **artificial intelligence** and **machine learning** community. **DARPA** announced in February that its **Air Combat Evolution program** executed the first live-flight demonstration of the **X-62A Variable In-flight Simulation Test Aircraft** in December 2022. The **U.S. Air Force Research Laboratory** leveraged lessons learned from the X-62A flights and in July demonstrated the first flight of its machine learning-trained algorithms on an unoccupied **XQ-58A Valkyrie**. In April, an AI technology jointly developed by Australia, the United Kingdom and the United States was demonstrated in a live trial on unoccupied intelligence, surveillance and reconnaissance systems. In September, the **U.K. Royal Navy** landed a **W Autonomous Systems autonomous transport drone**, named HCMC, onto the deck of the aircraft carrier **HMS Prince of Wales**. ★

Contributor: *Shawn Stephens*

READ THE APPRECIATION

ROBERT "BOB" SKELTON, TRAILBLAZER IN TENSEGRITY STRUCTURES, EXPERT IN DYNAMICS AND CONTROLS

READ THE APPRECIATION

MARTIN "MARTY" BRENNER, EXPERT IN AEROSERVOELASTICITY AND PIONEER IN CONTROL OF FLEXIBLE STRUCTURES

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 pre-processing, post-processing and infrastructure in support of computational simulation in the aerospace community.

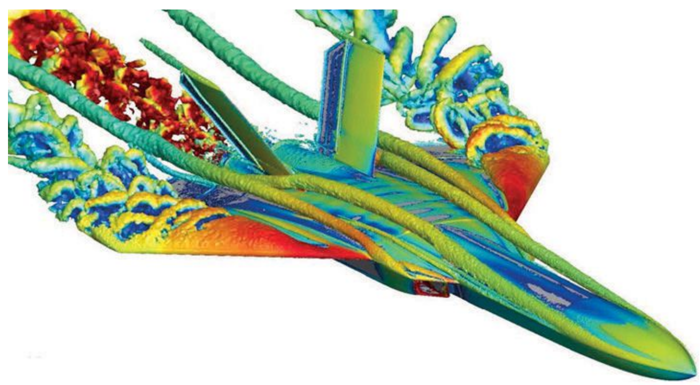
A number of new resources and capabilities were implemented and released this year across the meshing, visualization and computational environments community.

The version of **Fidelity Pointwise** released in January by **Cadence Design Systems** of California includes the ability to generate **mixed-order elevated meshes** for multiple computer-aided engineering formats. In May, the massively parallel polyhedral mesher **Stitch** was released as part of **Fidelity CharLES** by Cadence. Stitch uses a Voronoi diagram-based approach to generate cells with high regularity while being body fitted to complex geometries. This meshing approach also removes convexity constraints on cells near the boundary allowing length scales of the near-wall cells to be distinct from those of the underlying geometry. This enables the generation of coarse meshes for complex geometries without defeaturing the underlying computer-aided design representation.

A scheme developed this year at **NASA's Ames Research Center** in California enables automation of structured overset surface mesh generation, a process that typically requires extensive user expertise and effort. Decomposition of the surface domain is accomplished by the creation of face, edge and node meshes following the boundary representation topology of the geometry. This approach typically results in a much more fractured near-body grid system created in a few hours or less, compared to manually generated meshes that routinely take days or weeks. Testing of the new technique on multiple configurations, including the **Lift+Cruise vertical lift concept vehicle**, demonstrated that integrated aerodynamic loads, convergence rates, computational resources and efficiency are all comparable between manually generated grid systems and those created with the new technique.

The version of **Tecplot 360,** the visualization tool from **Tecplot Inc.** of Washington, released in August, includes a technique for visualizing isosurfaces and streamlines in high-order element solutions with reduced memory usage. The technique recursively subdivides high-order elements into smaller linear sub-elements in which the isosurface can be extracted using standard marching techniques. Memory usage is minimized by discarding unneeded sub-elements. Performance improvements approaching factors of up to 660 have been realized by computing the interpolation weights once at startup.

The **U.S. Department of Defense High Performance Computing Modernization Program** continued to expand and maintain an extensive array of supercomputers, high-speed and secure networking, and software development supporting the science and technology and test and evaluation communities within the military services. With the program on track to almost double compute resources available to the community in the coming year, two notable events occurred: The **Nautilus supercomputer**, containing over 176,000 AMD Milan processors, entered allocated service in August at the **Navy DOD Supercomputing Resource Center** at **NASA's Stennis Space Center** in Mississippi.



▲ This computed flow solution for the 5th Generation Aerial Target drone was created with Kestrel, the fixed-wing simulation tool CREATE-AV, the U.S. Defense Department's Computational Research and Engineering Acquisition Tools and Environments Air Vehicles project.

Robert Knapke/Arnold Engineering Development Complex

Also this year, the massive **Carpenter computer** containing over 277,000 AMD Genoa processors was delivered in July to the **U.S. Army's Engineer Research and Development Center** in Vicksburg, Mississippi. The computer is named for Medal of Honor recipient William "Kyle" Carpenter, a medically retired Marine Corps corporal wounded in Afghanistan.

By midyear, the transition of over 200 sites to the fourth-generation **Defense Research and Engineering Network** was completed, providing a 20-time increase in minimum bandwidth over the previous generation.

The **Computational Research and Engineering Acquisition Tools and Environments program** released new versions of all products in its suite of simulation tools supporting air, land and sea vehicle acquisitions. In particular, the **CREATE Air Vehicles** project released v12.3 of **Helios**, v12.7 of **Kestrel** and v3.0 of **ADAPT**, the rotary-wing simulation, fixed-wing simulation and conceptual design and optimization tools, respectively. The latest version of the **CREATE Meshing and Geometry tool, Capstone v12.3**, was also released in September, which adds an enhanced feature-based modeling capability. ★

Contributors: *William Chan, Scott Imlay and Carolyn Woeber*

Simulations underpin progress in advanced air mobility planning, standards for aerial refueling

BY CHRISTINE TAYLOR

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.

In August, Washington D.C.-based **Supernal**, in collaboration with the **University of California, Berkeley**, released details of **VertiSim**, a simulator designed to evaluate **electric vertical takeoff and landing** transportation networks. VertiSim can assess a diverse set of operational scenarios, encompassing varying fleet sizes, vertiport distances and parking pad setups and compute tradeoffs in passenger delay time, operational expenses and fleet utilization through comprehensive modeling of the intricate interdependencies inherent to **urban air mobility** systems. By striking a balance between passenger service quality and operational efficiency, VertiSim could help stakeholders make well-informed decisions regarding fleet size, network design and infrastructure development.

Mosaic ATM of Virginia, along with **Smart Sky Networks** of North Carolina and **GE Aerospace** of Ohio, flight tested the **Cloud Flight Management System** in June in Florida. The **CFMS** is a digital twin of a flight management system residing in a **cloud-based computing environment**. The system knows both the current state of an aircraft (including sensitive parameters, such as its weight) and, as it exists in a cloud computing environment, the entire state of the **National Airspace System**. Combining this information allows the CFMS to make quick decisions that are then passed to controllers and/or pilots for review. The live flight tests verified data exchanges and key CFMS functions but uncovered some new issues for future consideration. Flight test data revealed that reroutes requested by either a flight crew or controller, mediated by the CFMS, were completed within three minutes, including human reaction time to the CFMS-generated reroutes, as compared to an estimated eight minutes or more without the CFMS computations.

▼ In this photo, a Boeing MQ-25 refuels a U.S. Navy E-2D Hawkeye above Illinois in a 2021 test. Simulating refueling was one topic of discussion at the Aerial Refueling Systems Advisory Group's annual conference in April.

Boeing

In April, the **Aerial Refueling Systems Advisory Group** held its annual conference in Orlando, Florida. There were several papers presented on **aerial refueling dynamics, fuel system simulation and autonomous aerial refueling**. Of particular interest was the paper "A Modeling and Simulation Framework for Smarter Testing of Aerial Refueling Systems" by Ian Fialho of Boeing that discussed modeling and simulation standards for these mission-critical subsystems. The paper outlined an **interface standard** for the integration of **aerial refueling models** into a flight simulation environment, achieving a plug-and-play capability that could be shared across multiple vendors and platforms. The U.S. Defense Department's **Defense Technical Information Center** published the standard and supplemental updates on its website. It is the first set of modeling and simulation standards created in this domain.

Crown Consulting of Virginia, in partnership with **George Washington University** and several industry consultants in heliport infrastructure, received a $750,000 **Small Business Innovation Research Phase II award** from NASA in July to develop the **Vertiport Human Automation Teaming Toolbox**. V-HATT is designed for real-time human-in-the-loop simulations for vertiport arrival, surface and departure operations on the airside of a vertiport. **Human-machine teaming** is a core component of V-HATT, and the simulation toolbox will be designed to capture various teaming strategies with differing degrees of automation. The objective is to provide guidance to researchers, operators, manufacturers and infrastructure developers for realistic operational bottlenecks and vertiport capacity considerations for human roles.

In March, NASA announced **University Leadership Initiative Round 6 awards** totaling $25.1 million to four teams led by **New Mexico State University, Boston University, the University of Notre Dame and Tennessee Technological University**: a Mobility-Energy-Coordinated Platform for Infrastructure Planning to Support Advanced Air Mobility Aircraft Operations; Safe, Low-Noise Operations of Urban Air Mobility in Urban Canyons via Integration of Gust Outcomes and Trim Optimization; A Safety-Aware Ecosystem of Interconnected and Reputable Small Unmanned Aerial Systems; and Carbonless Electric Aviation. ★

Contributors: *Gano Chatterji, Ian Fialho and Fred Wieland*

Diagnostics, simulations and advanced facilities drive breakthroughs in plasma technology

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.

This year saw significant advances in laser diagnostics for various plasma applications. Researchers at **Colorado State University** and **Sandia National Laboratory** pioneered the use of **Thomson scattering** to measure electron temperature and density in high-power, laser-triggered switches, with applications to pulsed power. In February, researchers at **Texas A&M University** and **Georgia Tech** introduced a novel **Thomson scattering method with Bragg notch filters**. This approach enables one-dimensional electron temperature and density measurements, opening new avenues for exploring the spatiotemporal dynamics of low-temperature plasmas. In March, researchers at **Purdue University** demonstrated **resonance enhanced multiphoton ionization-Thomson microwave scattering** for diagnostics of electric propulsion devices, specifically targeting the measurement of krypton neutrals and ions in the exhaust plume of an ion engine. In May, researchers at **Princeton University**, in collaboration with the **Princeton Collaborative Low Temperature Plasma Research Facility**, developed a new method for calibrating **two-photon absorption laser-induced fluorescence measurements** of hydrogen atoms. The method is based on the complete dissociation of molecular hydrogen in hydrogen-xenon plasma and enables fast and reliable calibration for femtosecond, picosecond and nanosecond lasers. In June, researchers from **Texas A&M** and the **University of Michigan** conducted experiments in the **Hypervelocity Expansion Tunnel at Texas A&M's National Aerothermochemistry and Hypersonics Laboratory**, measuring nitric oxide formation behind a normal shock with **planar laser-induced fluorescence**. The measurements validated computational fluid dynamics simulations over a total enthalpy range of 7 to 10 megajoules per kilogram.

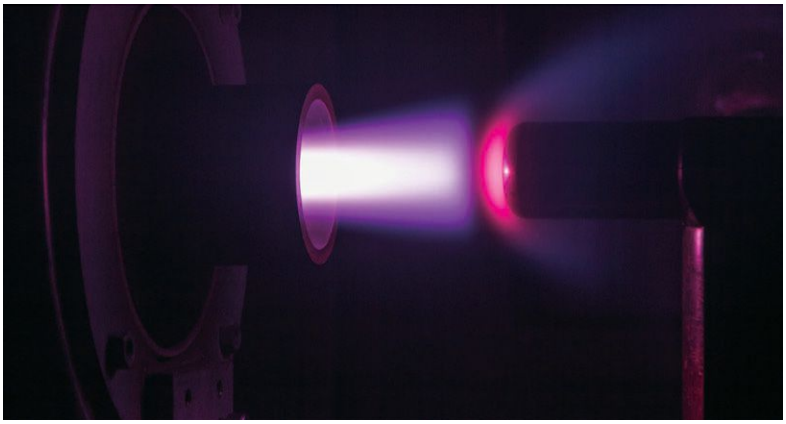
There were also advances in **computational plasma simulations**, with researchers utilizing a range of methods from fluid models to solutions of the Boltzmann equation. In January, researchers at the **University of Minnesota** performed **large-eddy simulations** of **plasma-assisted ignition** in static and flowing mixtures. They examined the effects of discharge pulse frequency on the probability of ignition, and the results largely lined up with the outcomes of previous experiments performed by colleagues at the **U.S. Air Force Research Laboratory** in Ohio. Also in January, **MIT** researchers developed a fluid model to explain experimental observations of both the increase and decrease in flame speed when influenced by nanosecond pulsed plasmas. The simulations revealed that the plasma accelerates the flame through kinetic effects and decelerates the flame through pressure perturbations. In June, scientists at **Princeton University**, in collaboration with **FAA**, modeled the effectiveness of a **surface nanosecond dielectric barrier discharge** for de-icing aerodynamic surfaces. The main effect of the plasma was volumetric gas heating in the boundary layer. Researchers at **Texas A&M** and the **Air Force Research Laboratory at Wright-Patterson Air Force Base** in Ohio led advances in modeling **rarefied flows**, where traditional fluid approximations can fall short. With the **direct simulation Monte Carlo method**, the team reproduced the standoff distance and geometry of a Mach 15 bow shock, matching wind tunnel measurements via the **Michelson interferometry technique**.

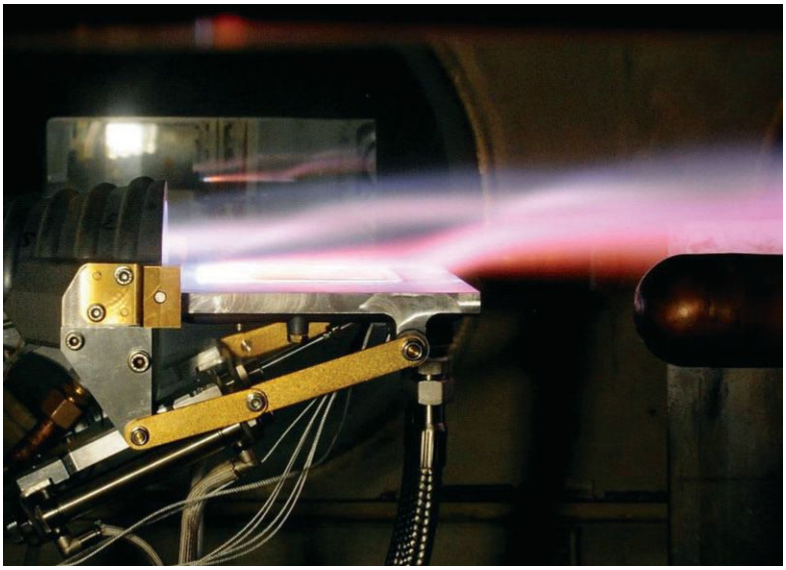
Researchers advanced science and technology leveraging facilities that replicate extreme conditions. In February, a team from **Princeton University** and **Combustion Science and Engineering Inc.** of Baltimore developed a **prototype ignition system for scramjet engines** based on nanosecond aperiodic discharge. The ignition system demonstrated efficient nonequilibrium plasma generation in large discharge gaps that mirror scramjet engine combustion chamber conditions. In August, scientists at **Princeton University** introduced a technique for studying pulsed nanosecond discharges in liquid via sub-nanosecond laser schlieren photography, revealing nano-void formation under the action of ponderomotive forces and discharge evolution in inhomogeneous media. Also this year, researchers at the **University of Stuttgart** in Germany operated their PWK4 arc jet facility with a hydrogen and helium mixture for the first time, simulating atmospheric entry conditions for giant planets. ★

Contributors: *Christopher M. Limbach, Stefan Loehle, Alexey Shashurin, Albina Tropina, Azer Yalin and Suo Yang*

▼ University of Stuttgart researchers ignited a hydrogen and helium plasma in the PWK4 facility in August to simulate atmospheric entry conditions of Uranus and Neptune. The distinctive red color of the plasma comes from the radiation of atomic hydrogen.

High Enthalpy Flow Diagnostics Group/ University of Stuttgart, Institute of Space Systems





Growing demand for flight data and plasma wind tunnels in Europe, U.S. to study reentry conditions

BY AARON BRANDIS AND ALESSANDRO TURCHI

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

▲ Researchers at the von Karman Institute for Fluid Dynamics in Belgium this year conducted the first campaign in the upgraded Plasmatron facility: testing a semi-elliptical nozzle in a supersonic flat-plate configuration. The aim of the ongoing research is to determine if the nozzle design can replicate relevant reentry conditions on test materials in terms of shear.

Bernd Helber/von Karman Institute for Fluid Dynamics

In January, NASA scientists started analyzing the performance of the **Orion crew capsule** that orbited the moon and returned to Earth in December 2022, as part of the **Artemis I mission**. Orion traveled farther into space than any previous crew-capable spacecraft and completed the first reentry at lunar return speeds for a crew-capable spacecraft since Apollo. The Orion crew module was instrumented with hundreds of sensors to measure aerodynamic, aerothermodynamic and thermal protection system performance during the module's reentry and landing in the Pacific Ocean. These instruments included thermocouples, radiometers and pressure transducers, which are part of the larger developmental flight instrumentation system that also includes structural and thermal sensors. The sensors are primarily used to reconstruct the flight environments and validate the assumptions, models and simulation tools used in the design process. Of particular interest were measurements taken that provide insights into boundary layer transition, surface catalysis, cavity heating, shock layer radiation, thermal protection material response, aerodynamic forces, moments and dynamic effects. The analysis of this data confirmed that Artemis I completed many of NASA's flight test objectives. The agency plans to refer to these analyses to make any required design updates and certify Orion for both **Artemis II**, scheduled for late 2024, and future planned crewed missions.

In May and June, the **von Karman Institute for Fluid Dynamics** conducted the first formal test campaign of the upgraded high-enthalpy 1.2-megawatt **Plasmatron**, located at VKI's facility in Belgium. As part of an ongoing **European Space Agency**-funded program on space debris characterization, VKI's **inductively coupled plasma wind tunnel**, which generates a plasma jet via electromagnetic induction, was equipped with two converging-diverging nozzles for testing at supersonic speeds in both stagnation point and flat-plate configurations. The flat-plate configuration, which aims to increase the shear induced on test materials, was achieved via a semi-elliptical nozzle designed at VKI — inspired by that of the **Interaction Heating Facility** at NASA's Ames Research Center in California — and manufactured by selective laser welding, a metal additive manufacturing technology. The test campaign, conducted by VKI for **R.Tech** of France under a separate ESA grant, demonstrated the potential of the flat-plate testing for studying common satellite materials that would melt, delaminate and/or "peel" when these spacecraft are dragged down into Earth's atmosphere at the end their operational lives. Ongoing activities include test campaigns on morphing materials and hot structures for hypersonic applications, as well as testing of thermal protection systems.

A record number of tests were conducted this year at two ICP wind tunnels of the **Center for Hypersonics and Entry System Studies** at the University of Illinois-Urbana Champaign. Since opening in 2022, nearly 500 tests have been conducted in these state-of-the-art facilities built by **Tekna Plasma Systems** of Quebec. Sixty tests were conducted in June alone. The tests — conducted under research and programs for the **U.S. Defense Department, Department of Energy, NASA** and **industry** — were for a breadth of research activities, from ultra-high temperature ceramics characterization to ablation response, material demisability, radiofrequency and infrared apertures performance, and hypersonic sensors development. One of the tunnels, the 350-kilowatt **Plasmatron X**, is the largest ICP facility in the U.S. and can produce flow regimes from subsonic speeds up to Mach 4 to emulate reentry conditions for Earth, Mars and Saturn's moon Titan, among other planetary bodies. The tunnel creates a chemically tailorable environment for novel research on thermal protection materials, gas-surface interactions and nonequilibrium phenomena. ★

Contributors: *Adam Amar, Charles Bersbach, Johathan Burt, Savio Poovathingal and Adam Whelan*

U.S. Army tests gravity airdrop, high-altitude parachutes and powered paragliders

BY KENNETH B. RICE

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** in June conducted a series of airdrops at Yuma Proving Ground in Arizona to demonstrate a technique for releasing four **Joint Light Tactical Vehicles** from a C-17, compared to two by the conventional method of having an extraction parachute pull each vehicle off the aircraft before the main parachutes deploy. JLTVs are heavier and larger than the **High Mobility Multipurpose Wheeled Vehicles** they are replacing, so while a C-17 can fit eight Humvees, currently only two JLTVs can be deployed from a C-17. Initial attempts to deploy four JLTVs at a time prevented the use of extraction parachutes, because the JLTVs and their platforms could strike the top of the cargo bay when exiting the C-17. The **Army Combat Capabilities Development Command Soldier Center, or DEVCOM-SC**, began looking for a solution last year with funding from **U.S. Transportation Command**. The decision was made to pitch the nose of the aircraft up 4 to 7 degrees so that gravity would extract each vehicle. During the drop tests, two four-door JLTVs and two weight tubs that simulated JLTVs were released. All payloads were deployed smoothly, and the JLTVs were fully operational after landing under their parachutes. This test proved that the gravity airdrop method of extraction can double the JLTV delivery capacity of a C-17.

In July, **DEVCOM-SC** conducted the first experimental deployments of high-glide ratio (greater than 5-to-1) parachute canopies under the **Precision and Extended Glide Airdrop System, or PEGASYS, project** funded by Transportation Command. The intent of PEGASYS is to demonstrate that **powered paragliders** can be deployed from military aircraft and carry payloads significant distances to the drop zone, while the aircraft stays far enough away to avoid becoming a target in contested logistics environments. The paraglider wings in the experiment were of a kind used commercially for ground takeoffs and had not been previously deployed from an aircraft. Initial engineering analysis by DEVCOM-SC and the contractor team of **Earthly Dynamics** of Georgia and **Aerial Delivery Solutions** of Florida led to several successful deployments. The goal of this testing was to build an initial understanding of paraglider air deployments to integrate these higher performance canopies into airdrop systems as part of DEVCOM SC's efforts to create multiple options for autonomous long-range precision aerial resupply in contested environments.

▲ This parafoil wing is a kind normally launched from the ground, but it was dropped from an aircraft over Yuma Proving Ground in Arizona to demonstrate air launch with a parachute that has a high-glide ratio of 5-to-1 while carrying 110 kilograms.

John Gildea/U.S. Army's Combat Capabilities Development Command Soldier Center

In the field of **high-altitude airdrops**, DEVCOM-SC in March tested airdrop systems at 35,000 feet, also at Yuma Proving Ground. Currently, no system is approved for deployment above 25,000 feet above mean sea level. An upgrade to **C-17s** created the opportunity for 35,000-foot aerial delivery, which would enhance the safety of the aircraft in contested environments. During the March testing, two different systems were tested. One was a **high-velocity container delivery system bundle**, a common airdrop cargo system for payloads of up to 2,200 pounds (about 1,000 kilograms) that utilizes a 28-foot **ring-slot canopy**. The other was the **High-Altitude Aerial Resupply System II**, a high-altitude deployment/low-altitude canopy for payloads up to 2,000 pounds. HAARS II is a two-stage system that uses a small parachute at high altitudes for payload stability before descending to a much lower altitude — approximately 1,200 feet — where a larger parachute slows the descent for a safe landing. The testing had mixed results with successes and failures for both systems. Challenges for airdrop deployments from high altitudes include changes in deployment dynamics (air density and faster speeds to maintain aircraft lift) and cold temperature impacts on electronics and hydraulics. ★

Contributors: *Shari Dangel, Usbaldo Fraire Jr., John Gildea and Andrew W. Meloni*

Airline profitability on the horizon after three turbulent years despite air traffic controller shortages

BY PRIYANK PRADEEP, SYED SHIHAB AND DAVID THIPPHAVONG

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

▲ NASA in January selected Boeing to build a Transonic Truss-Braced Wing demonstrator, shown here in an illustration. NASA and Boeing plan to fly the X-66A Sustainable Flight Demonstrator, as the aircraft was later designated, over the course of a one-year flight test campaign starting in 2028 to demonstrate that the truss-braced wing configuration can reduce fuel usage compared to today's single-aisle airliners.

Boeing

Following three consecutive years of losses primarily brought on by the **covid-19 pandemic** amounting to over $180 billion, the global airline industry is on track to post a profit of $9.8 billion this year, the **International Air Transport Association** projected in June. This can be attributed to the sustained growth in passenger air travel demand, which IATA projected to reach 87.8% of pre-pandemic levels this year, accelerated by the reopening of China's economy. By contrast, IATA reported that air cargo volumes, trending downward since March 2022, fell below pre-pandemic levels. The airline industry continues to face headwinds that include a tight labor market, elevated inflation levels, supply chain disruptions and high oil prices.

On the operations side, a shortage of **air traffic controllers** contributed to flight delays and cancellations this year, adversely impacting both airlines and the traveling public. In June, the **U.S. Transportation Department's Office of Inspector General** reported that staffing at 20 of 26 air traffic control facilities in the U.S. is below the 85% threshold prescribed by **FAA**. To address this shortage, Transportation Secretary Pete Buttigieg announced plans to recruit 1,500 controllers this year and 1,800 more next year. Also, to reduce the safety risks of signal interference from **5G** technology, FAA in May issued an airworthiness directive that prompted airlines to upgrade aircraft **radio altimeters**.

Substantial progress continued to be made toward routine **advanced air mobility** operations. In August, FAA published the "**Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Implementation Plan**," a year after the agency completed its UTM pilot program, in accordance with the requirements of the FAA Reauthorization Act of 2018. The plan is designed "to allow for the implementation of" UTM services "that expand operations beyond visual line of sight, have the full operational capability, and ensure the safety and security of all aircraft."

In May, FAA released an updated version of its **Urban Air Mobility Concept of Operations,** which included more detail on the use of the current regulatory framework to support initial operations and more information on various concept elements, such as flight corridors. In June, FAA granted **Joby Aviation** of California a **Special Airworthiness Certificate** to begin flight tests with its first production prototype, and in August did the same for **Archer Aviation** and its first **Midnight** air taxi.

Notable events in sustainable aviation include NASA's announcement in January of an award to **Boeing** to build and flight test a full-scale **Transonic Truss-Braced Wing demonstrator** to inform the development of the next generation of single-aisle aircraft, which comprise the majority of passenger airline fleets. The goal for the experimental aircraft — designated the **X-66A** in June by the U.S. Air Force — is to reduce fuel burn and emissions by as much as 30% relative to today's single-aisle aircraft by generating less drag through its longer and thinner wings stabilized by diagonal struts, and integrating technological advances in propulsion systems and materials.

In August, **Boom Supersonics** of Colorado received an **FAA Experimental Airworthiness Certificate** for its **XB-1**, a one-third scale demonstrator of its planned supersonic airliner **Overture**. Boom is targeting 2029 for entry to service. The Colorado-based company in May announced an agreement to purchase up to 5 million gallons of **sustainable aviation fuel** per year for Overture's flight test program from Dimensional Energy of New York.

Unoccupied air vehicles known as HAPs, short for high-altitude pseudo-satellites or high-altitude platform stations, could offer surveillance and communications services. In June, U.K.-based **BAE Systems** sent its **PHASA-35** into the stratosphere over New Mexico. Also in June, New Mexico startup **Sceye** completed its third test flight. Meanwhile, **SoftBank** of Japan tested a subscale model in March as part of developing its next-generation HAPS. ★

Contributor: *Tejas Puranik*

Hydrogen and electric aircraft make their mark

BY MICHAEL LOGAN AND MICHAEL DRAKE

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

The aircraft design world continues to expand the breadth of vehicle types achieving first flights. From new versions of older designs to new design types to new integrated sustainable propulsion concepts, the design world this year carries forward the long tradition of innovation.

In January, **Lockheed Martin** completed the first flight of the **Block 70 version of the F-16**. The company said that "total flight time was approximately 50 minutes and included airworthiness checks, such as engine, flight control and fuel system checks, as well as basic aircraft handling." Also in January, California-based **ZeroAvia** completed the first flight of its 19-passenger hydrogen-powered test aircraft. Using a **Dornier 228** airframe, the company retrofitted one of the **Honeywell TPE331** turboprop engines with a 600-kilowatt **hydrogen powertrain**.

Similarly, in March, **Universal Hydrogen** of California, flew a 40-passenger regional airliner on **hydrogen fuel cell propulsion**. The test airplane, nicknamed Lightning McClean, took off from Grant County International Airport in Washington and flew for 15 minutes, reaching an altitude of 3,500-feet mean sea level. The flight was made under an **FAA Special Airworthiness Certificate** and was the first in a planned two-year flight test campaign. The company is targeting 2025 for regulatory approval of passenger service of **ATR 72** regional aircraft converted to run on hydrogen. In the March test flight, one of the airplane's turboprop engines was replaced with Universal Hydrogen's fuel cell-electric, megawatt-class powertrain. The other remained a conventional engine for safety of flight.

In June, **Diamond Aircraft's DART-750** made its first flight in Austria. The aircraft is powered by a Pratt and Whitney Canada **PT6A-25C** turboprop engine and features a **Garmin 3000** avionics suite. The flight "lasted 30 minutes and covered all basic maneuvers, including performance and handling checks," Diamond said in a press release. Later in June, the **U.S. Air Force** made the inaugural flight of its first **Boeing T-7A Red Hawk** trainer in St. Louis. The flight lasted 1 hour, 3 minutes.

The following month, **Diamond Aircraft** was back in the news with the first flight of its **eDA40 all-electric aircraft**. The aircraft is powered by a Safran Electrical and Power ENGINeUS electric motor and equipped with a battery module from Utah-based Electric Power Systems. At the end of July, the **U.S. Air Force** made the first uncrewed flight using artificial intelligence algorithms in a three-hour sortie by an **XQ-58A Valkyrie,** developed by AFRL and Kratos Defense and Security Solutions. The flight took place at Eglin Air Force Base in Florida.

In September, Germany-based **H2Fly** flew its hydrogen-electric **HY4** demonstrator on liquid hydrogen for the first time. The company said the flight results indicate that liquid hydrogen doubles the range of the HY4 from 750 kilometers to 1,500 km.

In August, Colorado-based **Boom Supersonic** completed taxi tests with its subscale **XB-1** demonstrator and announced the receipt of an **FAA Experimental Airworthiness Certificate**, good indicators for a first flight in late 2023.

The **Rolls-Royce Pearl 700** turbofan received FAA certification in September, which Gulfstream said paved the way for the certification of its G700 and G800 aircraft by the end of the year.

In November, a **U.S. Air Force B-21 Raider** made its first flight out of Palmdale, California, marking the start of flight testing.

In January, **NASA** selected **Boeing** to build its **Sustainable Flight Demonstrator**. Later designated the **X-66A**, the heavily modified MD-90 airframe will have its original wings and engines replaced with the transonic truss-braced wing configuration. In August, the **Air Force** selected California startup **JetZero** to develop a full-scale blended-wing body flight demonstrator. Both projects aim to demonstrate technologies that will net significant gains in aircraft efficiency over conventional designs. ★

▼ The Block 70 version of the F-16 was among the aircraft to make a first flight this year. Lockheed Martin pilots flew the aircraft from the company's facility in Greenville, South Carolina.

Lockheed Martin

Aircraft operations welcomes new Concept of Operations and focus on sustainability

BY 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.

United Airlines and Archer Aviation, a California air taxi developer, are planning to begin passsenger flights in 2025. Passengers would be ferried between downtown Chicago and O'Hare International Airport.

Archer Aviation

In January, **FAA** published the **"Initial Concept of Operations for the Info-Centric National Airspace System,"** outlining how operations will look after 2035. This high-level ConOps describes how future NAS operations will support new paradigms without monolithic large systems through the introduction of "microservices" to perform all the critical NAS functions.

Urban air mobility is one of the new entrants that will need to be accommodated. In April, FAA published its "**UAM Concept of Operations Version 2.0**," which was followed by the start of the **UAM Airspace Management Demonstration project** in June. In collaboration with industry, this project showcased concepts described in the ConOps, including the creation and management of notional UAM corridors and architecture components that support information exchanges in the UAM ecosystem. Through the project, FAA is taking an iterative approach to demonstrate UAM operations and increasingly complex airspace management. Coordination was demonstrated between FAA, UAM operators, UAM service providers and public entities. Alongside this work to demonstrate the establishment and dissemination of UAM corridors, industry is moving forward with route definitions. California air taxi builder **Archer Aviation**, in partnership with **United Airlines**, in March announced a new route that will connect downtown Chicago to **O'Hare International Airport**. In June, **United Airlines** announced plans with **Eve Air Mobility,** a Brazil air taxi developer, to begin electric commuter flights throughout the San Francisco Bay Area, which includes working together to identify a route network.

Sustainability was also a theme for aircraft operations. In January, **NASA** established agreements with **Boeing** to deliver the **X-66A Sustainable Flight Demonstrator**, a **Transonic Truss-Braced Wing** aircraft with extra-long thin wings stabilized by diagonal struts. Boeing unveiled the livery for this aircraft in July at the **EAA AirVenture** air show in Wisconsin. NASA says X-66A is the first X-plane designed specifically to help the U.S. achieve **net-zero carbon emissions** for the aviation industry, a goal described in the 2021 U.S. Aviation Climate Action Plan. The idea is that flight tests and analysis of the aircraft could inform designs of future single-aisle aircraft, the backbone of passenger-based air travel. Single-aisle aircraft account for about half of aviation greenhouse gas emissions worldwide, according to NASA, so a design that requires less fuel could have a major impact on greenhouse gas emissions.

This year saw increased focus on **contrail avoidance** as another way of reducing aviation's climate impacts. In August, **American Airlines, Google Research and Breakthrough Energy** of Washington published results from a six-month study using **contrail forecast maps** developed by **artificial intelligence**. The airline was able to reduce contrail formation by 54% over 70 flights. Studies with other airlines and partners are ongoing to explore different forecasting approaches, along with impacts to fuel burn and flight time to assess the operational viability and importance of contrail avoidance strategies.

Midyear, the entire NAS (and Florida airports in particular) experienced significant delays caused by adverse weather conditions coupled with staffing shortages. This caused new scrutiny on **FAA's staffing challenges** and was discussed at multiple congressional hearings. Some of the issues experienced in Florida were also exacerbated by the increased pace of **commercial space launches**. In August, the number of fiscal 2023 launches had almost reached the total number of launches for the entirety of 2022. FAA projected 94 launches to be licensed in fiscal 2023 versus the 74 that occurred in fiscal 2022, an increase of 27%. ★

Contributors: *Tony Evans, John Koelling and Tom Reynolds*

▲ The Japan Aerospace Exploration Agency in May launched this B23-02 balloon from Australia carrying two experiments. One was the test version of a capsule for future sample return missions.

JAXA

Preparing for passenger balloon flights to the stratosphere and scientific flights to Venus

BY SARAH ROTH 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.

Commercial, academic and government entities made substantial scientific and technological advances in **high-altitude ballooning**. Early this year, New Mexico-based **Sandia National Laboratories and NOAA** completed a new **autosonde launcher** for hydrogen weather balloons in Utqiagvik, Alaska, reducing costs, mitigating supply concerns and providing weather data in new remote locations. Sandia's tethered-balloon system has provided near-continuous measurements of the atmospheric boundary layer at locations across North America. In May, Sandia researchers published recordings of infrasound measurements collected 21 kilometers above Earth's surface, a technique that could be applied on other planets.

In July, **NASA's Jet Propulsion Laboratory** began construction of an **aerobot prototype** with Near Space Corp. of Oregon for a planned mission to Venus. The prototype, an updated version of one tested in 2022, consists of an outer zero-pressure balloon with an inner super-pressure balloon designed to resist the acidic environment of Venus.

In a separate NASA-funded study to detect seismic activity on **Venus**, researchers in February analyzed data from a September 2022 field campaign consisting of 11 balloon flights in West Texas. This campaign detected acoustic signatures from barometers suspended on a balloon flying at an altitude of 18 kilometers.

In April, the **Super-pressure Balloon-borne Imaging Telescope** was launched via **NASA's Super-Pressure Balloon** from Wanaka, New Zealand. SuperBIT is a collaboration between Canadian company StarSpec Technologies, Durham University in the U.K., the University of Toronto in Canada, and Princeton University in New Jersey. The telescope's 40-day flight demonstrated the feasibility, practicality and robust performance of state-of-the-art balloon-borne imaging at a level that rivaled NASA's Hubble Space Telescope, setting a precedent for the scientific and technical capabilities of suborbital and near-space imaging platforms.

Also in April, the **Japan Aerospace Exploration Agency, JAXA**, began a campaign at the **Balloon Launching Station** in Alice Springs, Australia, with Australia's Commonwealth Scientific and Industrial Research Organization and NASA. Two balloon flights were conducted; the first was for a cosmic gamma-ray observation via an emulsion-film-type telescope. The other, an aerodynamic test of a capsule for future sample return missions, was the first drop test from a stratospheric balloon conducted in Australia. In July, JAXA performed a domestic balloon campaign at the **Taiki Aerospace Research Field** in Hokkaido, Japan. Researchers conducted four science flights, one of which was the first engineering flight of the U.S.-Japan Gamma-Ray and AntiMatter Survey mission.

In Florida, **Space Perspective** ramped up facilities and infrastructure to prepare for passenger suborbital flights aboard its **Spaceship Neptune** balloon and capsule. The company held a grand opening for its 4,500-square-meter Seely factory in August and began production on the first of many planned full-scale test SpaceBalloons. Manufacturing also commenced for Space Perspective's capsules, designed to seat eight passengers and a captain. Space Perspective also completed outfitting its **Marine Spaceport Voyager vessel**, which is to be a launch platform for capsules as well as a retrieval ship. Throughout the year, Space Perspective conducted several unoccupied test flights in preparation for the first passenger flight, targeted for 2024.

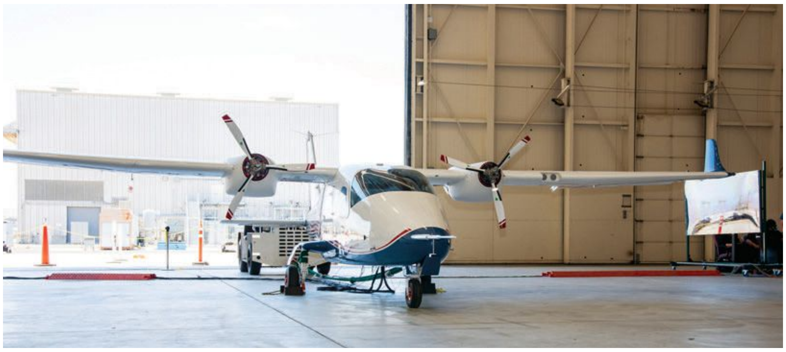
In June through August, the French and Canadian space agencies conducted their **Strato-Science campaign**, consisting of 150 scientists overseeing about 45 experiments. The agencies set up a new agreement late in 2022 for performing these balloon flights from Timmins, Ontario, meant to facilitate research flights for European and Canadian scientists for the next decade. For the 2023 campaign, the goal was to take advantage of the stratosphere's turnaround period and perform westward flights at the end of August, when there is no wind at high altitudes. These specific meteorological conditions allowed flights with atmospheric slow descent or stratospheric stable ceilings. ★

***Contributors**: Hideyuki Fuke, Mitzi Giles, Ashish Goel, Stéphane Louvel, Erika Roesler and Javier Romualdez*

Flight milestones and lessons learned from X-plane programs

BY PHILLIP ANSELL AND VIRGINIA STOUFFER

The **Electrified Aircraft 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.



▲ NASA repeatedly delayed the first flight date for its X-57 Maxwell electric demonstrator, and in September concluded the program without ever flying the aircraft. The X-57 is shown here undergoing high-voltage testing at Armstrong Flight Research Center in California in 2021.

NASA

NASA announced in June that it would halt development of its **X-57 Maxwell** demonstrator and in September concluded the program, aside from closedown work. Although this campaign had no flight tests, the agency said it served an instrumental role in advancing **aircraft electrification**. Researchers received a wealth of information from the integration of the fully electric propulsion system of this X-plane concept. Much of this information became an active component of the ongoing **NASA Electrified Powertrain Flight Demonstration** project. In July, program leads **GE Aerospace** of Ohio and **magniX** of Washington unveiled the livery of their EPFD test aircraft, which could fly as early as 2025.

Electric vertical takeoff and landing aircraft reached several milestones toward certification this year. In June, **Joby Aviation** of California received an **FAA Special Airworthiness Certificate**, allowing the company to begin flight tests with its pre-production air taxi to inform equipment qualifications required in certification for commercial flight. Joby plans to begin passenger service in 2025. Joby also secured an additional $55 million in funding from **Department of Defense** in April, and in September delivered an air taxi to Edwards Air Force Base in California for testing. Another California air taxi developer, **Archer Aviation**, received a **Special Airworthiness Certificate** for its **Midnight** air taxi and began testing in August. Archer announced a Defense Department contract worth up to $142 million in July.

Also in July, FAA released "**Modernization of Special Airworthiness Certification**," a notice of proposed rulemaking to redefine the **light sport aircraft** category. The current rule limits aircraft weight to 1,320 pounds (599 kilograms). FAA instead proposed performance-based measures, allowing aircraft that are almost two and a half times bigger, with a doubling of potential airspeed, and removing the single reciprocating engine requirement for any number and type of propulsors so that both electric and powered lift could be included. The requirements would allow for non-paying passengers to be carried, or for cargo and surveillance work.

Hydrogen-electric aircraft power systems made significant leaps this year. In January, California-based **ZeroAvia** flight tested its modified **Dornier 228** testbed aircraft. The company replaced one turboprop engine of the configuration with a hybrid fuel cell/battery powertrain. In March, **Universal Hydrogen** of California flew a modified **De Havilland Canada Dash 8** aircraft, which also had one turboprop engine replaced with a **hydrogen-electric powertrain.**

Several electrified aircraft configurations demonstrated progress at the **Paris Air Show** in June. French company **VoltAero** displayed its **Cassio 330** hybrid-electric aircraft, scheduled to make its first flight this year. Known for its fully electric propulsion design, **Eviation** of Washington secured letters of intent for 50 aircraft during the show. New entrant **Aura Aero** of France secured multiple memorandums of understanding with operators to acquire its hybrid-electric aircraft configuration. **SolarStratos** of Switzerland also debuted its **solar-electric aircraft** concept, which the company intends to fly at high altitudes to acquire scientific data of the Earth's atmosphere and climate.

New academic programs for electrified aircraft were established under **NASA's University Leadership Initiative** program. In March, the **Carbonless Electric Aviation, or CLEAN**, project was awarded to Tennessee Technological University under ULI Round 6. This project focuses on the development of **solid oxide fuel cell systems** coupled with **combustion-driven turbogenerators** to produce electricity from ammonia. The **Center for High Efficiency Electrical Technologies for Aircraft project** at the **University of Illinois, Urbana Champaign** was awarded a $4 million Phase II grant to continue work in developing prototypes of hydrogen-electric aircraft technologies for future zero-emissions systems. A ULI team led by Ohio State University completed a five-year NASA-funded effort on electrified propulsion technologies. This campaign concluded this year with a test at the **NASA Electric Aircraft Testbed** in Ohio, where the team attempted to run at full power and prove that the power electronics worked under altitude conditions. ★

Contributor: *Amy Jankovsky*

First flights and diverse applications headline 2023 activity

BY ANDY FREEBORN, KARL GARMAN AND JESS PETERSON

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

Multiple commercial space companies conducted milestone test flights. In April and May, **Virgin Galactic** flew its **VSS Unity** spaceplane to the edge of space. In June, the company flew its first paying passengers, marking the transition from research and development to commercial operations. As of November, the company had completed five tourist flights. In November, **SpaceX** launched its second Starship-Super Heavy. Shortly after stage separation, Super Heavy exploded, with Starship continuing on for several minutes before it was lost at an altitude of 148 kilometers. **FAA** announced it would oversee a "mishap" investigation of the flight, led by SpaceX. During the April inaugural flight, the rocket exploded about four minutes after liftoff.

Numerous programs began flight testing this year. In January, **F-35** fleet modernization progressed with the first flight of the **Technology Refresh 3** configuration at **Edwards Air Force Base** in California. In April, the **Air Test and Evaluation Squadron 23** at **Naval Air Station Patuxent River** in Maryland released the first two-weapon salvo of **Stormbreaker** bombs from an **F-35B**. In June, a U.S. Air Force pilot flew a **Boeing T-7A Red Hawk** for the first time, and in November, the first T-7A was delivered to Edwards. The T-7A was designed to replace the service's fleet of 1960s-era T-38 Talons. The same week, the first flight test of a **B-21 Raider** was conducted. The aircraft reportedly departed from **Air Force Plant 42** in Palmdale, California. In a press release, the Air Force stated that "flight testing is a critical first step in the test campaign managed by the Air Force Test Center and 412th Test Wing's B-21 Combined Test Force."

▼ The first B-21 Raider was flown in November at Palmdale, California, the start of a planned multiyear flight campaign. The U.S. Air Force is targeting the late 2020s for the first of these Northrop Grumman-built bombers to enter service.

Thomas Jordan

Among the milestones were breakthroughs in artificial intelligence. In July, the **Air Force Research Laboratory** in Ohio conducted the first flight of machine learning-trained AI algorithms on an **XQ-58A Valkyrie**, developed by AFRL and Kratos Defense and Security Solutions. The flight built on the testing announced in February by DARPA that AI agents had piloted the **X-62A** research aircraft in a series of December 2022 flights. Conducted under DARPA's Air Combat Evolution program, these flights demonstrated that AI-driven autonomy agents could perform advanced fighter maneuvers on the X-62A aircraft, including a live versus live engagement of an AI-controlled X-62A against a human-piloted F-16.

Progress also continued toward operational hypersonic weapons. In January, the Air Force and DARPA concluded the **Hypersonic Airbreathing Weapon Concept** program with the final flight of the Lockheed Martin version of the missile. Powered by an Aerojet Rocketdyne scramjet, the vehicle met all objectives — traveling "at speeds greater than Mach 5, higher than 60,000 feet, and farther than 300 nautical miles," DARPA said in a press release. The HAWC program significantly increased the amount of U.S. scramjet flight test data, and the missile technology was transitioned to the Air Force and Navy acquisition organizations.

There were several first flights in the area of hydrogen-electric propulsion. In January, **ZeroAvia** flew its modified **Dornier 228** aircraft, and in March, **Universal Hydrogen** of California flew its modified **De Havilland Dash 8**. The companies applied similar risk mitigation strategies by replacing only one of the two turboprop engines on their aircraft with a hydrogen fuel cell powertrain. Flying from Moses Lake, Washington, Universal Hydrogen completed a five-flight campaign in June and then ferried the aircraft to the new test location in Mojave, California. ZeroAvia completed its initial campaign of 10 flights in July. Both companies are aiming to lower the emissions of today's aircraft by selling kits for operators to retrofit their regional aircraft with hydrogen fuel cells and electric motors. ★

Contributors: *Cody Hydrick, Andrew Knoedler and Shawn Stephens*

General aviation community advancing toward a sustainable future

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.

General aviation community activity surpassed pre-pandemic levels and made significant strides toward a sustainable future. In April, **FAA** released its annual report **"Air Traffic by the Numbers."** The agency recorded 26.4 million **general aviation flight hours** for 2021, compared to the 25.6 million hours reported for 2019. There were 209,200 **active general aviation aircraft** across the U.S. in 2021, up from 204,100 in 2020. For 2022, the number of active pilot certificates increased by 5% to 756,927, and **remote (or drone) pilot certificates** increased by 19.5% to 304,256. At the end of 2022, there were 5,175 **public use airports** and 14,332 **private use airports** across the country. General aviation is defined as the manufacture and operation of any type of aircraft that has been issued an airworthiness certificate by FAA, other than aircraft used for scheduled commercial air service or operated by the military. This definition includes on-demand **Federal Aviation Regulations Part 135** operations.

Advancements in **sustainable propulsion** continued to make inroads into the mainstream market. In July, **Diamond Aircraft** conducted the first flight of its all-electric **eDA40** at its headquarters in Wiener Neustadt, Austria.

California-based **ZeroAvia** made the first flight of its **Dornier 228 hydrogen-electric** test aircraft in January and concluded the initial flight test campaign with the 10th flight in July. The Dornier 228 aircraft uses a hydrogen fuel cell power generation and electric propulsion system, resulting in zero carbon emissions.

▲ A Gulfstream G700 test aircraft flew at an average speed of Mach 0.89 from Savannah, Georgia, to Tokyo, a new speed record for general aviation aircraft. Gulfstream has predicted FAA type certification of the G700 design could occur by the end of the year.

Gulfstream

In May, a **Gulfstream G700** using a **sustainable aviation fuel** blend set a speed record, traveling from Savannah, Georgia, to Tokyo at Mach 0.89. This followed the late 2022 flight in which a **Gulfstream G650** flew on 100% SAF — a first for the business-jet industry toward the goal to achieve net-zero carbon dioxide emissions by 2050. The SAF for the 2022 flight was a two-component mixture provided by **World Energy** of California, which derived the fuel from waste fat and plant oils, and **Virent Inc.** of Wisconsin, which used plant-based sugars to create synthesized aromatic kerosene.

Joby Aviation of California made progress toward receiving an **FAA type certificate** for its **S4** air taxi, a four-passenger **electric vertical takeoff and landing** aircraft. Joby said in February that it had completed the second stage of certification, in which the company identified the ways it would meet the safety regulations identified in the first stage of certification. In July, Joby said it had submitted its stage three certification plan describing the analysis and testing needed to demonstrate compliance. In September, Joby announced the selection of Dayton, Ohio, as the site for its first aircraft production facility. Plans call for manufacturing up to 500 aircraft per year.

In July, **Reliable Robotics Corp.** of California received FAA approval of the certification plan for its **continuous autopilot engagement system** for automatic taxi, takeoff and landing operations. The company wants to install the flight control technology into **Cessna Caravan 208s** for cargo flights and eventually passenger flights. In the near term, plans call for flight tests, as outlined in the certification plan. ★

Hypersonics manufacturing scales up and international allies engage

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.

In academia, March saw the inauguration of the **Plasmatron X facility at the University of Illinois Urbana-Champaign**. The 350-kilowatt plasma wind tunnel is the largest in its class in the U.S. In May, the **National Natural Science Foundation of China** announced the opening of its **JF-22 hypervelocity facility**. This 167-meter-long shock tunnel can replicate flows up to Mach 30 with nozzle exit diameters of 2.5 meters. In June, **Purdue inaugurated** the **Hypersonics and Applied Research Facility**. The 6,000-square-meter building is home to the Mach 8 quiet wind tunnel and the hypersonic pulse reflected shock/expansion tunnel. In July, the **University of Colorado Boulder** broke ground for the construction of its **plasma wind tunnel**. Over the last four years, an average of three new academic hypersonic wind tunnels have opened annually.

The biggest standout trend in hypersonics this year was related to shoring up the U.S. supply chain and scaling up of manufacturing for expendable hypersonic systems. In March, **President Joe Biden** signed a presidential determination to rebuild and expand the nation's domestic hypersonics industrial base. In May, the **National Defense Industrial Association** released a report outlining the needs of the industry and workforce. In July, **Raytheon** was awarded an $81 million contract for the **Hypersonic Air-breathing Weapon Concept**, and **Dynetics** of Alabama was awarded a $428 million contract to develop the **Common Hypersonic Glide Body prototypes**. In August, **Northrop Grumman** opened a new hypersonic propulsion system manufacturing factory. Also that month, **Huntington Ingalls** outfitted Zumwalt-class destroyers with the **U.S. Navy's Conventional Prompt Strike missiles.**

Internationally, several new hypersonics programs were announced by allied democratic nations. In April, Japan awarded **Mitsubishi Heavy Industries** a $2.8 billion contract to develop a series of missiles, and South Korea approved a $2 billion investment to develop hypersonic interceptors. In July, the U.K. announced it would invest approximately $1 billion to develop hypersonic strike capability. In August, the U.S. and Japan announced a cooperative agreement to begin a **Glide Phase Interceptor Cooperative Development program**.

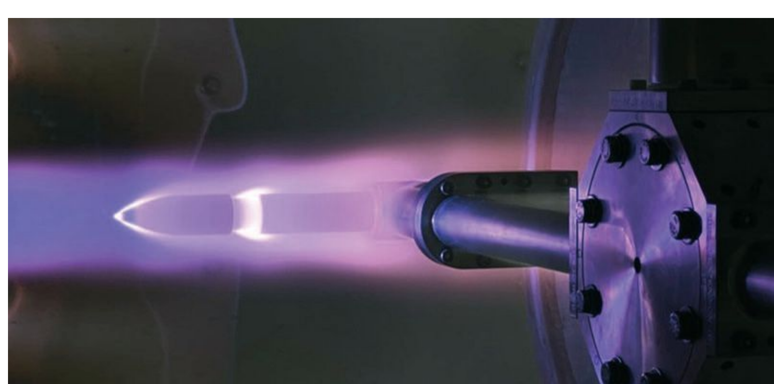
In February, China reportedly conducted a flight test of its **DF-27 intermediate range ballistic missile**, in which the vehicle flew 2,100 kilometers in 12 minutes equipped with a hypersonic glide vehicle. In May, the trial began for three Russian hypersonics scientists charged with sharing classified information with China. On the battlefield, Ukrainian forces claimed to have downed a Russian **Kinzhal missile**, via U.S. Patriot missile intercept. In June, Iran reported that it has developed a Mach 15 hypersonic missile. In August, North Korea conducted its 18th missile test of the year. Additionally, hackers reportedly working for the North Korean government breached systems at NPO Mashinostroyeniya, a Russian maker of hypersonic missiles and satellites.

In the commercial realm, progress by hypersonics startups spanned new funding to flight tests. In May, **Stratolaunch** released the first prototype of a **Talon-A hypersonic testbed** from the Roc carrier plane. June saw progress from three startups: Swiss company **Destinus** flew its **Jungfrau prototype** with a hydrogen afterburner for the first time; **Airbus Ventures** announced an investment in **Venus Aerospace** of Texas; and Massachusetts-based **Specter Aerospace** completed full-scale testing of its plasma-igniter augmented scramjet engine. In August, Australia-based **Hypersonix** announced an exclusive teaming agreement with **Kratos** to market the **DART AE hypersonic test platform**. In September, **Castelion** announced a $14 million seed round; this California startup is working on low-cost hypersonic weapons. In November, **Hermeus** of Georgia received a multiyear contract from the U.S. Defense Innovation Unit to mature its hypersonic aircraft subsystem and mission system technology. For the first year of the contract, Hermeus will receive $23 million. ★

Contributors: *Felipe Gomez del Campo, Sassie Duggleby, Matt Leibowitz, Frank Lu, Francesco Panerai and AJ Piplica*

READ THE APPRECIATION

DON WILSON, A GROUNDBREAKING FIGURE IN HIGH-SPEED AERODYNAMICS



▼ In March, the University of Illinois Urbana-Champaign inaugurated the Plasmatron X facility. As of early November, 600 runs were made in this inductively coupled plasma tunnel across approximately 20 test campaigns.

University of Illinois Urbana-Champaign

Air Nostrum, a Spanish regional airline, plans to purchase 20 airships from Hybrid Air Vehicles for passenger flights starting in 2027.

Hybrid Air Vehicles

Buyers commit to ordering up to 35 hybrid airships for passenger and freight operations

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.

In November California-based **LTA Research** began outdoor testing of its carbon fiber-framed dirigible, **Pathfinder 1**. In the coming months, **P1** will undergo masted and free flight tests, approved by FAA under a **Special Airworthiness Certificate** granted in September. In June, LTA CEO Alan Weston was a keynote speaker at **AIAA's Aviation Forum** in San Diego, where he explained the breakthroughs in materials and manufacturing embodied in the airship. P1 initially will be propelled by **diesel-electric power**, but Weston said that plans call for later transitioning to **hybrid-electric propulsion**. He said this will provide the entire aviation community with the chance to see the potential of hydrogen as a power source.

In September, **Hybrid Air Vehicles** of the U.K. announced the signing of a memorandum of understanding with BAE Systems' advanced research division, **FalconWorks.** The companies plan to assess security and defense applications for HAV's planned **Airlander 10** hybrid airship. In August, Spanish regional airline **Air Nostrum** doubled its 2022 order of 10 airships to reserve a total of 20 Airlander 10s. Air Nostrum plans to ferry up to 100 passengers at a time on Airlanders flying Mediterranean routes starting in 2027. HAV is targeting 2026 to begin manufacturing Airlander 10s in Doncaster, England, whose mayoral authority announced in March that it would invest 7 million pounds ($8.7 million) toward production.

In June, airship operator U.K. company **Straightline Aviation** signed a letter of intent to buy three airships — with an option to buy 12 more — from **AT Squared Aerospace**. This California startup was formed in March and licenses the intellectual property for what had been **Lockheed Martin's LMH-1** hybrid airship, now renamed Z1.

In April, **Flying Whales** of France announced it had selected the **Honeywell 1-megawatt generator** as the power source for its proposed **LCA60T** hybrid-electric airship, designed to carry 60 tons of cargo. Whales has signed cooperation agreements with some 30 prospective users, including logging companies and makers of products ranging from wind turbines to rockets.

In January and February, a **Chinese balloon** entered U.S. airspace, alarming officials and sparking debate about its nature and intent. After the craft was shot down by a **U.S. Air Force F-22 Raptor** in early February and the debris inspected, National Security Council spokesman John Kirby told reporters that the balloon was able "to speed up, to slow down, and to turn. So, it had propellers, it had a rudder." In other words, it was not a drifting balloon but a navigable airship.

In September, consultant Phil Kornbluth discussed the outlook for the helium market with the Lighter-than-Air Technical Committee. Although rising prices and limited supply characterized the U.S. helium market this year, Kornbluth predicted that prices will fall and supply will increase in coming years. By decade's end, he predicts an oversupply of the gas. Another lifting gas, hydrogen, remains abundant, at about one-third the cost of helium.

In May, Simon and Schuster published **"His Majesty's Airship,"** in which author S.C. Gwynne retells the life and 1930 death of England's **R101**. Chapter 2, titled "Brief History of a Bad Idea," dismisses any possibility that airships were or ever could be a viable means for transporting human beings, logs or anything else. Asked if he might change his mind if he stepped outside someday to see the skies black with Airlanders, P1s, Z1s or Flying Whales, Gwynne was reluctant to say yes. ★

▲ The U.S. Government Accountability Office in April upheld the U.S. Army's selection of Bell Textron's V-280 Valor tiltrotor for its Future Long-Range Assault Aircraft program. Here, a V-280 test aircraft flies over Arlington, Texas.

Bell Textron

Future long-range assault aircraft and advanced air mobility leading the way

BY ERASMO PIÑERO JR.

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

The U.S. Army's **Future Long-Range Assault Aircraft program** and **advanced air mobility** initiatives are the two driving forces behind advances in **powered lift** as we near the end of the first quarter of the 21st century.

In February, **Lockheed Martin's Sikorsky** protested the U.S. Army's December 2022 decision to award the contract for the FLRAA program to **Bell Textron** for its **V-280 Valor** aircraft. The U.S. Government Accountability Office denied the protest in April, clearing Bell to continue work on the V-280 preproduction test vehicles. The V-280 is powered by two **Rolls-Royce T406** turboshaft engine derivatives. The Army plans to bring the new aircraft into service in 2030 in anticipation of retiring its **UH-60 Black Hawk** helicopter fleet, carrying out one of the largest aviation modernization programs of the past two decades.

Accentuating the excitement around the **AAM aircraft** in development by various companies (including many startups), California-based **Wisk** in July demonstrated its fifth-generation electric air taxi demonstrator, **Cora**, at the **EAA AirVenture air show** in Oshkosh, Wisconsin. The remotely supervised aircraft flew without a pilot on a predetermined path, demonstrating agility, positive control, vertical flight and transitional flight capabilities. Wisk is targeting the late 2020s to begin ferrying passengers aboard a fleet of remotely piloted air taxis, but other air taxi developers plan to begin passenger service with piloted aircraft in the next few years.

Certification and validation procedures and their accompanying certification rules continue to be a major challenge for air taxi developers, many of whom have chosen **electric vertical takeoff and landing, or eVTOL**, designs. As an example, **FAA** in June published a series of regulatory guidelines aimed at providing the AAM community with a path forward for the eventual certification and training of aircrews (for vehicles that require onboard control). However, the proposed rules generated lots of discussion within the vertical flight community, and as of November had not been finalized. The requirements are an outgrowth of FAA's decision late last year to classify eVTOLs in a **"powered-lift" category**, meaning these vehicles will not be treated as airplanes. The proposed rules further mandate that pilots have an additional **powered-lift category rating**, rather than allowing helicopter and airplane pilots to add a type rating to their existing certificates.

In August, NASA's **Ingenuity Mars Helicopter** resumed flights on Mars after it was grounded following an emergency landing during a July 22 flight. During that flight, No. 53, NASA controllers determined that Ingenuity encountered a surface feature that prompted its flight computer to command an immediate landing. NASA believes the emergency landing procedure was triggered because images from Ingenuity's navigational camera did not match data from the inertial measurement unit. With 66 flights completed as of early November, scientists believe Ingenuity will continue gathering useful Martian topographic data beyond its expected life span. ★

Space and aviation sectors invest in community awareness, training and education to ward off increasing cyberattacks

BY KRISHNA SAMPIGETHAYA, PHILIP POTTS AND ARUN VISWANATHAN

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

The year began with an outage of the **Philippines air traffic management system** in January and an outage of **FAA's Notice to Air Missions system** in February, both of which disrupted and delayed air travel. While these incidents are not considered cyberattacks, they point to underlying critical system vulnerabilities, such as inadequate security policies and outdated cyber infrastructure, that may be exploited by an adversary.

Cyberattacks this year continued to demonstrate real-world impacts on the aviation and space sectors. An analysis of the **European Organization for the Safety of Air Navigation** published in July showed an increase in supply chain security incidents in which exploitation of a vulnerable third-party vendor's system caused data breaches at an airport or airline. A cyber threat event map in the analysis also showed hacktivists were the dominant aviation cyber threat actor and that **distributed denial-of-service, or DDoS**, attacks were the most common threat to airlines, airports and international aviation authorities. For example, DDoS attacks by pro-Russian hacktivist groups in January targeted airports in NATO member countries and allies, particularly those located in countries that supplied Ukraine with armaments and training.

In February, the **European Union Aviation Safety Agency** revised one of its safety alerts to note an increase in spoofing and jamming of GNSS, **global navigation satellite systems** including GPS, in certain geographical regions and conflict zones, and provided mitigation recommendations. The effects of **GNSS jamming and/or spoofing** in some cases caused unsafe flight scenarios that required aircraft rerouting or additional pilot guidance.

▼ Among the cyberattacks this year was a May data breach of an American Airlines and Southwest Airlines third-party vendor that stores personal information of pilot applicants. The airlines reported that the information of nearly 9,000 individuals was accessed.

American Airlines

New strides were also taken toward improving cyber defenses. In April, it was reported that the **U.S. Office of the National Cyber Director** held a workshop with satellite manufacturers to raise awareness about securing satellites against cyberattacks and engaged experts from industry, government and academia to address policy gaps in safeguarding space from hackers. In June, a cybersecurity working group kicked off an international technical effort to build a more secure-by-design space sector. This IEEE standard for space system cybersecurity would provide requirements for securing space systems, including ground stations and spacecraft, and "establish trustworthiness criteria amongst various elements of the space systems ecosystem," according to the working group's webpage.

As threats increase, governments and companies are increasingly acknowledging the security risk and investing in training and education. In August, the **Aerospace Village** met at **DEF CON 31**, which included the U.S. Air Force and Space Force's **Hack-A-Sat** capture-the-flag competition. For the first time, five international teams of security researchers ethically hacked a satellite orbiting around Earth at 5 miles per second. Their mission was to establish a data link, capture a ground target image, download it to a ground station and overcome satellite-imposed restrictions while defending against other teams' attacks. The Italian team mcHACKeroni was declared the winner.

Also during this conference, a capture-the-flag event was held with the **Aviation Information Sharing and Analysis Center**, in collaboration with **Embry-Riddle Aeronautical University**. Participants tackled problems resulting from simulated cyberattacks at a major airport. **Boeing, Lockheed Martin and SpaceX** also presented capture-the-flag challenges related to commercial aircraft, military aircraft and satellites, respectively.

Formal education courses were also offered throughout the year, including the **International Civil Aviation Organization** aviation cybersecurity course offered by Embry-Riddle, the **International Air Transport Association** course, and **Indiana University's Kelley** space-cybersecurity digital badge. ★

Communications satellites proliferate into an expanding multi-orbit domain

BY RABINDRA "ROB" SINGH

The **Communications Systems Technical Committee** is working to advance communications systems in space applications.

▲ Thirty-six satellites for Eutelsat OneWeb's broadband constellation were launched in March aboard a Launch Vehicle Mark-3 developed by the Indian Space Research Organisation. The launch completed the Gen 1 constellation, comprised of 618 satellites.

Eutelsat OneWeb

This year continued the expansion of satellite launches across multiple orbits. In August, **BryceTech** of Virginia reported that 2,500 satellites were launched in 2022, up from 1,800 in 2021 and 1,300 in 2020. Communications was the primary mission for 80% of those satellites.

For **low-Earth orbit**, constellations comprised the majority of launches. As of October, **SpaceX** launched 1,600 satellites for its **Starlink** broadband constellation, **Eutelsat OneWeb** of the U.K. launched 132 broadband satellites, **Planet Labs** of California 36 satellites, **Swarm Technologies** of California 12 and **Spire Global** of Virginia three. In October, the first two prototypes for **Amazon's planned Project Kuiper constellation** were launched. Plans call for launching 1,800 satellites by mid-2026 and deploying all 3,236 by 2029.

There were a number of developments for emerging **LEO direct-to-device service**, in which satellites would provide communications directly to and from cellphones. **Apple** announced in February that it financed **MDA** of Canada to manufacture 17 **Globalstar satellites**, scheduled to be launched in 2025 to support iPhone SOS emergency services already rolling out via the existing Globalstar network. In January, **Inmarsat** of the U.K. announced an agreement with California-based **Viasat** to develop satellite connectivity for smartphones; **Inmarsat** of the U.K. and **Viasat** of California announced a similar agreement in April. In May, Texas-based **AST SpaceMobile** announced successful demonstrations with its **BlueWalker3 prototype**, proving that the satellite can relay calls in 4G and 5G. In August, **Lynk Global** of Virginia began **direct-to-device 5G service** via its three satellite "cell towers." **SpaceX** committed to offering direct-to-smartphone service starting in 2024 with text and then voice and data in 2025.

In April and September, a combined 28 **Tranche 0 satellites** were launched for the **Space Development Agency's Proliferated Warfighter Space Architecture**. Following the 2022 awards for 126 transport and 35 tracking **Tranche 1 satellites**, SDA in August awarded contracts for a combined 72 **Tranche 2 Transport Layer satellites** to **Northrop Grumman** and **Lockheed Martin** and in October awarded contracts for another 100 Tranche 2 satellites to **York Space Systems** and **Northrop Grumman**.

In June, the **European Commission** selected a consortium made up of **Airbus Defence and Space, Eutelsat, Hispasat, SES and Thales Alenia Space** to build spacecraft for its planned **IRIS2** multi-orbit constellation.

For **medium-Earth orbit**, the third and fourth **SES O3B mPower** satellites were launched in April. Electrical issues discovered shortly after launch prompted SES in October to announce that **Boeing** will build two additional O3B satellites for launch in 2026. The fifth and six O3B satellites were launched in November. In September, **Intelsat** reported that it will decide early next year whether to develop its own MEO constellation to provide communications services starting in 2027.

For **geosynchronous equatorial orbit**, large satellite builders continued to compete for orders. Fewer than 10 orders were placed this year, down from the average of 20 in past years. In July, Maryland-based **Hughes Network Systems' Jupiter 3** was launched, marking the heaviest communication satellite in orbit. The satellite, built by **Maxar Technologies** of Colorado, provides 500 gigabits per second for broadband services. **Viasat** struggled, announcing in August that its **Viasat-Inmarsat-6 F2** launched in February suffered a total power loss. Also, its **Viasat-Americas-3** satellite launched in May experienced partial loss due to an antenna failure. Fewer awards for flexible software-defined satellite solutions were made, including for **Airbus Onesat** and **Thales Inspire** satellites designed to provide operators flexibility and hedges against unpredictable market shifts. Fortunately, there was an increase in smaller, 1-2-kilowatt-class micro-GEO satellite awards for reduced services: The first **Astranis** satellite launched in May, and the company secured additional awards. Also in May, **Inmarsat** ordered three satellites from **SWISSto12** of Switzerland.

These advances in LEO, MEO and GEO pave the way for expanding applications into cislunar and lunar orbits, and the coalescence of nonterrestrial networks demonstrates this emerging integrated multi-orbit space domain and suite of communications services. ★

Innovations in spaceflight computing tempered by semiconductor manufacturing

BY RICK KWAN

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

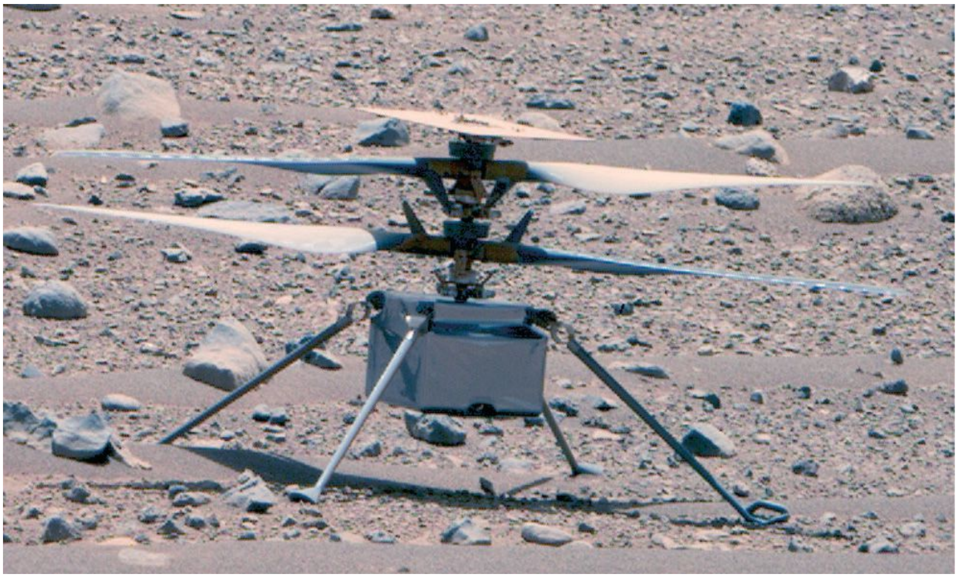
In October, NASA's **Ingenuity Mars Helicopter** rose to 24 meters (about 79 feet) above the Martian surface, the highest altitude Ingenuity had reached as of November in any of its 66 flights so far. It has outlasted its design as a technology demonstrator and survived a Martian winter.

Ingenuity's flight control and autonomous operation is enabled by a three-level fault-tolerant avionics computing stack that mixes commercial, industrial and military-grade components. A **Qualcomm Snapdragon** designed for smartphones runs **Linux** to handle visual navigation, data management and telemetry. It connects to two **TI TMS570 Hercules** safety processors designed for automotive applications; these transform sensor data into flight control. They connect to a **ProASIC3** radiation-tolerant **field-programmable gate array, or FPGA**, board that talks directly to sensors and the rotor interface. NASA upgraded Ingenuity's software in November 2022 so that the helicopter could better avoid hazards and allow flights over riskier terrain this year. In horizontal flight, elevation can rapidly decrease as the ground rises quickly to meet the helicopter.

Silicon for **NASA's High Performance Spaceflight Computing processor** is in full development at **Microchip Technology** of Arizona. The HPSC chip is a multicore implementation of the **RISC-V** architecture with vector extension. Initial device samples are expected in 2024. Early this year, Microchip began shipping quarterly software development kit, or SDK, updates to lead customers and partners. The SDK includes a software emulator of the HPSC processor, a toolchain-similar to LLVM and Linux kernels. With these, customers and partners can prototype software for HPSC in advance of device samples being available. In addition, Microchip is working with system and interconnect partners in **VITA-78 SpaceVPX** and the **Sensor Open Systems Architecture** to ensure that the ecosystem of space avionics hardware is available for HPSC. HPSC is expected to be at least 100 times faster than current spacecraft computers. Furthermore, the RISC-V vector extension could enable workloads with highly parallel computation, which benefits increased spacecraft autonomy.

Despite the U.S. Congress passing the Creating Helpful Incentives to Produce Semiconductors and Science Act of 2022, **Taiwan Semiconductor Manufacturing Co.** chairman Mark Liu said in July that the company's first **advanced semiconductor foundry**, or fab, in the U.S. would not come online until 2025, citing a shortage of skilled workers. The **CHIPS and Science Act** provided $52 billion in federal funding for manufacturing and research incentives. The **Semiconductor Industry Association** said in December 2022 that the legislation sparked upwards of $200 billion in private investments in U.S. semiconductor production. However, SIA also called attention to "the significant shortage of STEM workers facing the semiconductor sector and the entire U.S. economy" as well as access to global markets.

Constructing the fab building itself is the easy part. Installing and testing cutting-edge lithography equipment, specialized robotics, plumbing and networking in a large high-quality cleanroom environment are more difficult and require STEM workers. It is almost like assembling and testing an interplanetary spacecraft. **Taiwan Semiconductor Manufacturing Co.** broke ground on a fab building in Arizona in April 2021. It was expected to be operational in 2024, with a second one in 2026. Most of TSMC's fabs are in Taiwan, less than 100 miles from the Chinese mainland. **Apple's most advanced smartphone chips** are manufactured there. So are **NVIDIA's parallel processing chips** that are fueling the vast bulk of the revolution in artificial intelligence. **Intel** broke ground on two fabs in Ohio in September 2022 but expects them to be operational in late 2025. ★



▼ In April, NASA's Ingenuity Mars Helicopter reached two years of operations on the Martian surface. As of early November, Ingenuity had flown 66 times and reached a maximum altitude of 24 meters.

NASA/JPL-Caltech/ASU/MSSS

▲ An XQ-58A Valkyrie flew in July controlled by artifical intelligence algorithms developed by the Air Force Research Laboratory. The unoccupied aircraft flew for three hours followed by a piloted F-15E.

U.S. Air Force

Powered by Moore's Law, AI-enabled automation makes headway toward certification

BY YEMAYA BORDAIN, JOHN MORA AND MIRA STOYANOVA

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

As the computing world grieved the passing of **Gordon Moore** in March, the aerospace industry reflected on the many innovations in digital avionics made possible by the increased processing power that Moore predicted would double every two years. Without such an increase, now-burgeoning **artificial intelligence-enabled systems** would not exist. From military achievements in autonomy to civil regulatory milestones, this year saw many developments that owe their existence to the ever-expanding computing power that Moore foretold.

The start of **advanced air mobility** operations will usher in denser and more complex airspace, requiring onboard systems to make real-time decisions by analyzing and processing enormous amounts of information while maintaining low size, weight and power. In February, **Intel Corp.** and Swiss company **Daedalean** released the white paper **"The Future of Avionics: High Performance, Machine-Learned and Certified"** to demonstrate for the first time how to ensure that a machine learning-based system can simultaneously meet computational and size, weight and power limitations as well as certification requirements. It laid out a reference architecture — a specific list of requirements to create the right types of computers — for certifiable embedded electronics, and described the challenges of applying software assurance to a machine-learned device. This approach paves the way for a new generation of airworthy equipment driving the aviation industry's need for high-performance embedded computing.

In March, **Kaman Corp.** of Connecticut and **PHI Aviation** of Louisiana announced they will partner to develop the **KARGO UAV** for commercial cargo operations. The quadcopter will feature onboard **autonomous flight control software** from Pennsylvania-based **Near Earth Autonomy**, which previously provided AI-driven autonomous flight systems for Kaman's **K-MAX TITAN** optionally piloted helicopter for the U.S. Marine Corps. In May, the **U.S. Air Force** selected Near Earth Autonomy to establish a reliability standard for **autonomous aerial transport** that defines the processes necessary for meeting regulatory, insurance and end-user assurance demands.

In April, **Xwing** of California initiated the certification process for its **Superpilot** autonomous flight control system, which the company wants to install aboard Cessnas for pilotless cargo delivery. The company submitted a **Project Specific Certification Plan** to **FAA** for a standard category certification project for a large uncrewed aircraft system. Equipped with electro-optical and infrared cameras, radars and lidars, Superpilot uses **AI** to facilitate autonomous takeoff, landing and in-flight collision avoidance. Should cargo flights prove successful, Xwing plans to install Superpilot on passenger aircraft.

In July, the **Air Force Research Laboratory** conducted the first flight of **machine learning-trained AI algorithms** on an unoccupied aircraft. The three-hour test flight with an **XQ-58A Valkyrie,** developed by AFRL and Kratos Defense and Security Solutions, included the algorithm solving "a tactically relevant 'challenge problem' during airborne operations," according to an AFRL press release. This was the culmination of millions of hours of testing, including high-fidelity simulation events, sorties on earlier model drones, hardware-in-the-loop events and ground test operations to mature the algorithms to assure safety in the field.

Also in July, the **European Aviation Safety Agency** conducted a **stages of involvement audit** on what it says could be the first certified machine learning-based safety-related application. Developed in a partnership between Florida-based **Avidyne** and **Daedalean**, the **PilotEye** traffic awareness system uses machine-learned algorithms to process and analyze video from aircraft-mounted cameras to track nearby airborne objects. PilotEye can detect noncooperative traffic such as drones, hot air balloons and birds, which do not transmit transponder signals alerting to their presence. The audit follows the **Concepts of Design Assurance for Neural Networks reports** co-authored by **Daedalean and EASA** and could demonstrate the **W-shaped learning assurance approach** as an acceptable means for compliance. ★

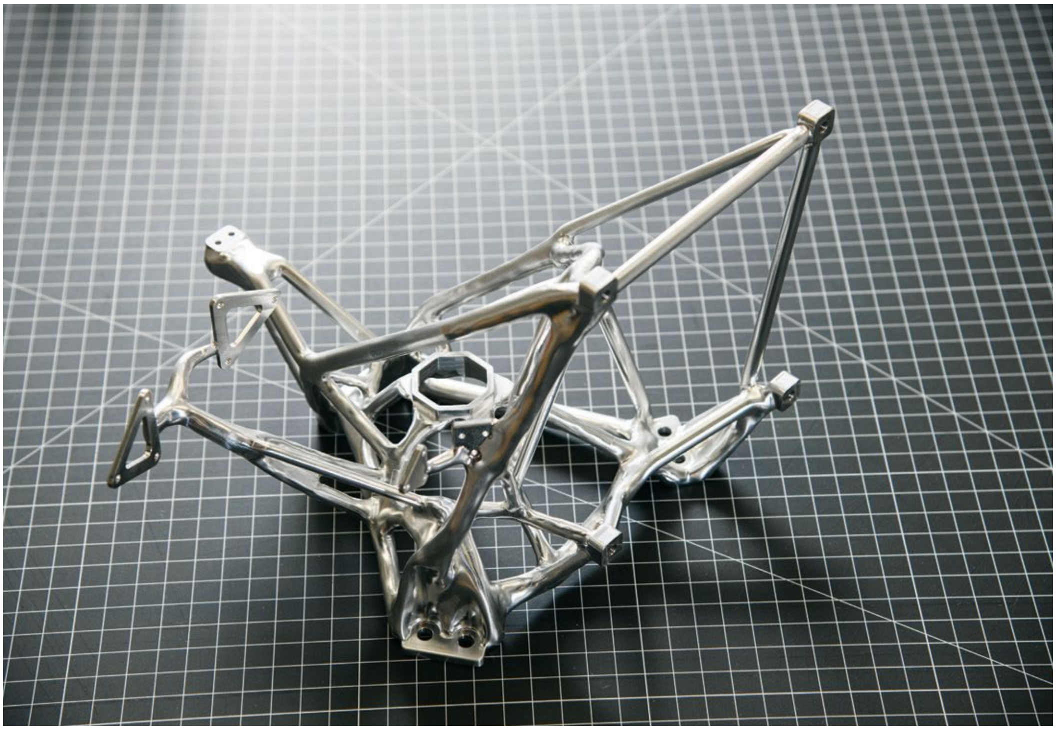
READ THE APPRECIATION

GORDON MOORE, CREATOR OF MOORE'S LAW AND A PIONEER IN SEMICONDUCTOR TECHNOLOGY

Artificial intelligence begins to demonstrate the potential to revolutionize aviation

BY WILLIAM C. JOHNSON

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.



▲ A NASA engineer at Goddard Space Flight Center in Maryland designed this 3D-printed structural mount with the aid of commercially available artificial intelligence software. Dubbed "evolved structures," these components are up to two-thirds lighter than structures made through computer-assisted design methods. NASA

Although academics and researchers have studied **artificial intelligence** for decades, this year saw AI enter our collective consciousness through tools for generating art, music and video, the ubiquitous discussions on chatbots, and the ethics of using AI to perform human tasks. As a result of revolutionary advances this year, several commercial sectors, including the aviation industry, chose to embrace AI through investment and broader collaboration.

In February, **NASA's Goddard Space Flight Center** in Maryland announced the development of a new engineering design process that incorporates generative AI into traditional **computer-aided design, CAD**, modeling to produce new "evolved structures" that adhere to design requirements provided by an engineer. Engineers can iterate on the designs as the human-machine teaming interfaces continue to mature, and then these models can be additively manufactured for use in NASA missions. This is particularly useful for optimization of mission parameters where a nontraditional shape might provide a novel solution that would not have appeared through conventional design templates.

There was increased interest by aviation regulators and airworthiness authorities for the safety assurance of AI in aircraft. Researchers have worked for years on novel AI-enabled applications for aircraft, but providing safety assurance for these new tools has been a challenge, particularly for human-machine teaming systems. Federal agencies are sharing best practices for safety assurance of AI elements on their own aircraft and looking for ways to adapt aviation standards to support the entire aviation community.

In May, the **European Aviation Safety Agency published** its **"EASA Artificial Intelligence Roadmap 2.0 — Human-Centric Approach to AI in Aviation,"** a key reference for providing context on key AI-related considerations as the aviation community learns more about the potential of new human-machine teaming tools. Standards development organizations such as **SAE International** of Pennsylvania, the **European Organization for Civil Aviation Equipment**, **ASTM International** of Pennsylvania and **RTCA** of Washington, D.C., are active in this domain and sometimes coordinate with one another for AI standards in aviation.

At the **Connected Aviation Intelligence Summit** in September, Tassio Carvalho, the American Airlines senior manager for AI/machine learning, declared that "AI will be everywhere" and said that American Airlines is looking at ways to use AI to support its operations. At the summit, many of the potential applications of AI-enabled technologies focused on using AI as an assistive technology to support the humans in the systems.

In February, **DARPA** kicked off its **AI Forward** program to focus on bringing government, industry and academia together to explore new directions for AI research for national security. Human-machine teaming is one of the key research areas within the program that will be essential to creating trustworthy systems. ★

Information and command and control systems play pivotal role in modern warfare

BY JIMMIE MCEVER AND ALI RAZ

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.

▲ SpaceX Starlink satellites have provided Ukrainian forces with internet connectivity during the war with Russia. Shown here is the first batch of the latest version, the V2 Minis, launched in February on a Falcon 9.

SpaceX

This year saw the reinforcement and emergence of trends that have significant implications for the future of command and control. Work continues in the U.S. national security sector to develop advanced strategies and novel concepts for C2 in inherently joint (meaning cross service-branch), multinational and multidomain operations.

The U.S. Defense Department's **Joint All-Domain Command and Control, JADC2,** strategy is one of the most prominent, complex and high-stakes efforts by the department to modernize the underlying foundations of information and command and control systems, IC2S. JADC2 aims to give joint force commanders rapid control of military assets and information across all operational domains (space, air, land, sea and cyber), regardless of the service that owns the assets and with the aid of artificial intelligence. The **U.S. Government Accountability Office** in January published a report, "Battle Management: DOD and Air Force Continue to Define Command and Control Efforts," noting that the department has yet to release details, such as "which existing systems will contribute to JADC2 and what future capabilities need to be developed." In July, the **U.S. Army** announced plans to modernize its communication networks to support the JADC2 program, while the **National Defense Industrial Association** held a special conference devoted to JADC2.

In operational matters, the war in **Ukraine** continued to yield insights for IC2S. The nature of the involvement of the commercial sector appears more direct in this conflict than has been observed in the past, particularly in the information technology and cyber aspects. **Commercially produced drones and commercial off-the-shelf equipment** made significant contributions to the Ukrainian warfighting effort. They have supplemented military C2 and intelligence, surveillance and reconnaissance systems and have brought to light the importance of interoperability across a wider range of systems.

One insight from Ukraine is that commercial providers can grow wary of providing services for warfighting, and this can create a dependency risk. Consider **Starlink**, SpaceX's internet satellite megaconstellation. As the war unfolded, Starlink provided reliable **space-based networking** and **internet connectivity** for the Ukrainian people and the Ukrainian military response, even as the traditional communications infrastructure of the nation was damaged by the invading forces. This capability enabled the preservation of robust connectivity for Ukrainian forces, which was critical for their distributed and agile concept of operations but also created a source of risk — as demonstrated by **Starlink's denial of network use** for a Ukrainian operation in Crimea, as described in Walter Isaacson's biography, "Elon Musk," published in September.

Nevertheless, Starlink's performance highlighted the potential of new digital, network and AI-enabled modes of intelligence, surveillance and reconnaissance that integrate and synthesize data from multiple sources to create a situational awareness advantage. The constellation enabled citizens to report sightings of Russian forces via an app, and this information was shared with intelligence officials via a digital map, according to a commentary by Steven Feldstein on the "War on the Rocks" website.

Also, the experience in Ukraine has highlighted the attractiveness of C2 capabilities and command posts as targets for adversary action. Ukraine forces have damaged and displaced Russian C2 capabilities, forcing Russian C2 to be conducted increasingly from "standoff" range, impacting its effectiveness and responsiveness. **Russian-sponsored cyberattacks** attempted to disrupt Ukrainian commanders' communications by targeting Starlink-enabled battlefield links. Maintaining agile and effective C2 in the face of kinetic and cyber threats will be a continuing challenge.

Events this year in Ukraine and elsewhere demonstrated the rapidly evolving landscape of command and control. Understanding and dealing with these opportunities and challenges will be a key focus of the Information and C2 Systems Technical Committee in the coming year. ★

A year of machine learning demonstrations and validations for aerospace applications

BY KERIANNE HOBBS

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

▲ A Stanford University research group conducted a field test with their prototype ReachBot in May. In a lava tube in the Mojave Desert, an analog for lava tubes on Mars, ReachBot gripped the side of the tube with the claw-like appendage at the end of its extendable arm. Plans call for the operational version of the robot to climb vertically and around obstacles such as large rocks, maneuvers not possible with today's wheeled rovers.

Stanford University

This year, there were several significant advances to enable machine learning on air and space systems. Early in the year, engineers with the **Aerospace Corp**. demonstrated the pose estimation system aboard **ExoRomper**, a reprogrammable machine vision testbed hosted on Aerospace's **Slingshot-1** satellite in low-Earth orbit. ExoRomper has a visible camera pointed at a maneuverable miniature spacecraft. The payload captured upwards of 1,000 images of the spacecraft in a variety of poses and processed a subset of images onboard to estimate the spacecraft's pose, using a combination of **machine learning** and **Perspective-n-Point algorithms**. The remaining images were used to train new machine learning models to be uplinked to improve the pose estimation accuracy and raise the technology readiness levels to support satellite proximity operations.

In February, **DARPA** announced two machine learning aviation firsts that were demonstrated by its $72 million **Assured Autonomy program**, which is developing design-time and run-time technologies to ensure safe operation of neural networks in flight software. Program activities included the first-ever demonstration of autonomous airfield taxi operations to follow a "follow me" automobile and another airplane at a commercial airport, and the first use of neural networks to reroute a general aviation-sized aircraft in the National Airspace System. Both demonstrations used flight software on a Boeing-Cessna Grand Caravan autonomous demonstrator assured with DARPA program technologies.

In April, **NASA's Jet Propulsion Laboratory** in California, **Ubotica** of Ireland and **Hewlett Packard Enterprise** of Texas completed their two-year validation of 60 applications on the **Snapdragon 855 Mobile Hardware Development Kit** and **Intel Myriad** edge processors and **Spaceborne Computer-2** rack computers onboard the **International Space Station**. These algorithms included instrument data processing, including synthetic aperture radar image formation; image and data analysis including machine learning classifiers; and resource scheduling and dynamic targeting. This validation included both general purpose computing and graphical processing unit, digital signal processing and neuromorphic (convolutional neural network) hardware to establish benchmarks against traditional flight processors like the **Rad750** and **LEON4**.

In May, a **Stanford University** research group developing robotic locomotion for extreme environments conducted a field test in a lava tube in the Mojave Desert in California. The robot, **ReachBot**, is an ongoing research project in the **Autonomous Systems Lab, Biomimetics and Dexterous Manipulation Lab**, and **Earth and Planetary and Surface Processes group** at Stanford. ReachBot is designed to explore Martian lava tubes by using extendable booms instead of traditional robot arms or legs to climb vertical, overhanging and obstacle-laden terrain. At the end of each boom is a microspine gripper, a claw-like appendage containing several arrays of needles to catch on asperities of rough surfaces, and a stereo camera for autonomous grasp identification. For this project's debut field test, a partial ReachBot prototype consisting of an extendable boom, stereo camera and microspine gripper identified and grasped targets in the lava tube.

In September, the **Vehicle Systems Manager and Autonomous System Management Architecture** for **NASA's Lunar Gateway**, a planned moon-orbiting space station, completed a critical design review at **NASA's Johnson Space Center** in Texas. The VSM is the vehicle-level integrated control system that will support tactical functions such as fault management, resource optimization and management, mission management, and timeline execution for Gateway. The VSM is expected to enable a significant reduction in ground operations contact hours with Gateway, particularly during extended uncrewed periods, by bringing unprecedented autonomous systems capabilities onboard the human spacecraft. ★

Contributors: *Steve A. Chien, Alonzo E. Lopez, Stephanie N. Newdick, Jim Paunicka and Julia Badger*

Expansion of sensor networks continues to improve military security and civilian mobility

BY EZEQUIEL JUAREZ GARCIA, ALI RAZ 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.

▲ The U.S. Space Force in February announced that the 10th and final GPS-III satellite is "available for launch." A GPS-III is shown in Lockheed Martin's Denver facility.

Lockheed Martin

The U.S. Space Force's efforts to expand and harden its satellite network achieved several key milestones this year. In January, **HawkEye 360**, the Virginia-based radio-frequency data analytics company, was awarded a contract to identify potential RF threats to **GPS** services. A month later, the **Space Force** announced it had accepted delivery of the 10th and final **GPS-III satellite** from **Lockheed Martin**, the latest generation of the GPS satellite constellation. The force's **Space Systems Command** announced in April a "focus on the maturation of [missile warning/missile tracking] sensors, optical satellite cross-links, data fusion, ground communications and constellation mission management" for **Epoch 2**, the second installment of its missile warning satellite network.

In other satellite network developments, **SpaceX** began upgrading its **Starlink** constellation to **V2 Mini satellites** in late February. These second-generation satellites form part of Starlink's growing constellation of nearly 5,000 low-Earth orbit satellites and provide four times more capacity than earlier iterations, according to SpaceX.

In August, **NASA** released its **Strategic Implementation Plan 2023** detailing the Aeronautics Research Mission Directorate's future of aviation for the next 25 years. Among its strategic thrusts, ARMD plans to aid the development of **vertical lift aircraft** to bolster support for **advanced air mobility**, including development of electric cargo aircraft and air taxis. ARMD also plans to focus on **in-time systemwide safety assurance**, a proactive safety strategy to address emerging aviation risks, and assured autonomy. Combined, these two thrusts will provide the national airspace with the safety, capacity and efficiency it needs to accommodate increasingly autonomous aircraft. According to NASA, this will require the use of "advanced sensors and networks."

On the topic of next-generation tactical fighters, in January, the **F-35 Joint Program Office** confirmed that the "U.S. Air Force, Navy, and Marine Corps are jointly developing and integrating an advanced radar for the F-35 Lightning II." This new radar system will be installed in **Block 4 A/B/C variants** of the F-35. The F-35 JPO announced in late March a one-year delay of the F-35's **Technology Refresh 3**, which was due in April of this year. The modernization of the F-35 with TR-3 is "intended to load the jet with improved displays, computer memory and processing power" and is planned before the release of Block 4. The new technology in TR-3 will increase the tactical fighter's data-fusion capabilities.

In parallel developments, **Turkey's Defense Industry Agency** released images in March of the Turkish Aerospace Industries' **TF-X stealth fighter** on a runway. This full look comes after images of the prototype emerged December of last year. The TAI TF-X is reported to have an infrared search and track sensor system to provide long-range, high-accuracy threat detection in areas where radar is not an option. TAI plans to deliver 20 TF-X Block 10 aircraft by 2028, with an estimated unit price of $100 million. ★

New software technology released for advanced air mobility, spaceflight and artificial intelligence

BY STEVEN M. LINCOLN

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

The aerospace sector made significant strides this year in melding **artificial intelligence and machine learning** with aviation practices, spurred by regulatory evolutions and collaborative endeavors.

In February, the **European Union Aviation Safety Agency** unveiled the **"EASA Concept Paper: First usable guidance for Level 1&2 machine learning applications,"** a deliverable under the EASA Artificial Intelligence Roadmap. The paper's release accentuates the growing role of machine learning applications in aviation, given that it builds on the prior Level 1 guidance for applications in which the full authority always remains with human decision-makers. The paper delineates guidance for developing and deploying AI/ML-based systems in safety-critical applications. It can be understood as a software development standard, akin to DO-178C, but with a focus on AI/ML software, which cannot be certified using DO-178C alone. The updated information focuses on Level 2 applications, emphasizing "human-machine collaboration" for automated decision making under human supervision.

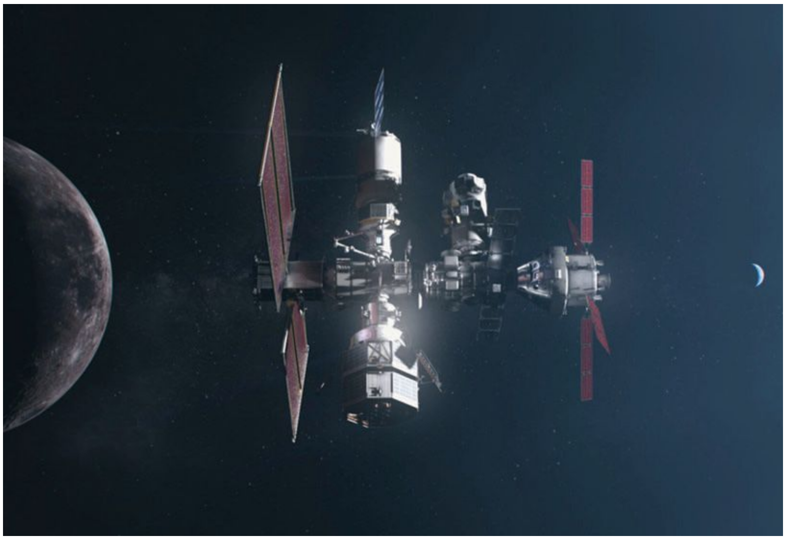
In July, **DLR, the German Aerospace Center**, concluded **HorizonUAM**, a three-year study of **urban air mobility**. DLR analyzed multiple aspects but placed emphasis on safe autonomy of upcoming air vehicles. For this, DLR analyzed the new AI regulations from EASA and standards from the SAE G-34/EuroCAE WG-114 working group in the context of UAM. Researchers identified and exemplified **operational design domain** supervision in the regulatory framework to secure the AI component via a safe operation monitor, or SOM. DLR held an international symposium in July at its **National Experimental Test Center for Unmanned Aircraft Systems** to discuss the project results. Among other results, the SOM software demonstrated its ability to supervise an AI function during test flights. This approach can support the safety of future UAM and drone operations.

In May, **EuroCAE**, a nonprofit that develops standards for civil aviation, initiated the **WG-127 Lower-risk Aviation Applications working group**, which includes experts from **DLR, Garmin Ltd., Rolls-Royce, and the Software Technical Committee**. The goal is to develop a new software standard for lower risk applications, meaning one that is independent and does not require specialized knowledge of DO-178C, the current standard for safety-critical software development in aerospace, but one that can be very demanding to meet for low-risk-use cases. This effort will therefore largely benefit the uncrewed aircraft industry, as well as general aviation.

In July, **Iowa State University's Laboratory for Temporal Logic in Aerospace Engineering** developed and released the C implementation of **R2U2 Version 3.0**, the first spaceflight-certifiable, real-time, open-source, runtime verification engine. R2U2 stands for Realizable, Responsive, Unobtrusive Unit, a reference to the major capabilities a runtime verification engine must have to achieve flight certification and run onboard embedded systems. R2U2 V3.0 incorporates capabilities required for monitoring the **NASA Lunar Gateway Vehicle System Manager software**. The VSM team this year integrated R2U2 V3.0 into the flight software. R2U2 V3.0 also incorporates a new graphical user interface and requirements validation mechanisms. R2U2 continuously monitors system operating requirements expressed in mathematical logic, providing provably correct, real-time evaluations of these requirements on the currently running system.

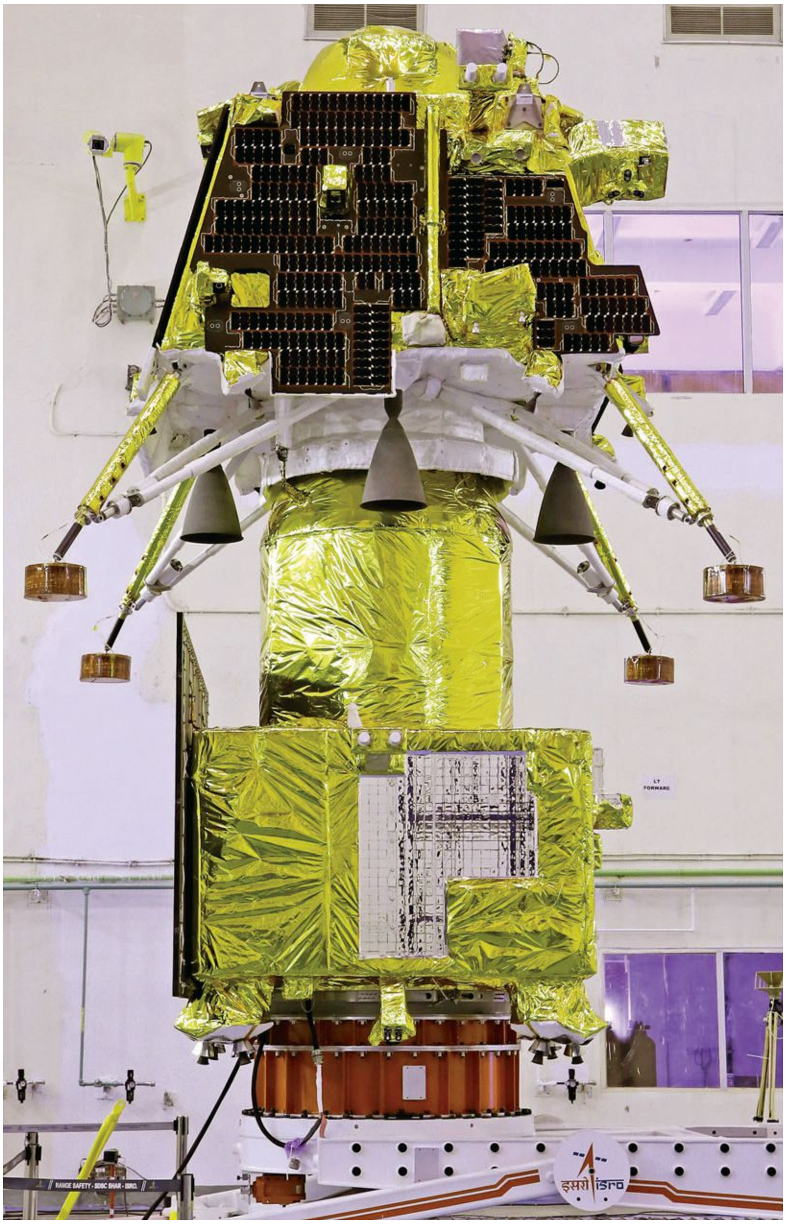
The **C-130J Joint User Group, U.S. Special Operations Command, and C-5 Air Force Life Cycle Management Center** under the Air Force Materiel Command this year initiated negotiations with **Lockheed Martin Aeronautics Air Mobility and Maritime Missions** to establish a software factory in order to release software to their member aircraft more frequently and with more content flexibility. This relationship between C-130J operators and Lockheed Martin will provide capability to the fleet at the speed of need. ★

Contributors: *Kristin Yvonne Rozier and Christoph Torens*



▼ An illustration of NASA's planned Lunar Gateway space station. The agency this year integrated the R2U2 Version 3.0 verification engine into the flight software that will manage the instruments and components of Gateway as it orbits around the moon.

NASA



▲ The Indian Space Research Organisation's Vikram lander, shown here ahead of its July launch, touched down near the lunar south pole in August under the Chandrayaan-3 mission.
Indian Space Research Organisation

Exploration endeavors beyond Earth's orbit

BY GIANG LAM

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.

In September, **NASA's Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer, or OSIRIS-REx**, returned samples from the asteroid **Bennu**. OSIRIS-REx released its capsule, which parachuted to a landing in Utah. It was the first U.S. mission to collect and return samples from an asteroid. The spacecraft and its capsule, built by **Lockheed Martin**, were launched in 2016 to rendezvous with Bennu, which is 1.36 astronomical units away from Earth at the farthest point in its orbit. OSIRIS-REx descended toward the surface of Bennu in 2020 and collected an estimated 250 grams of rock and dust. Leading up to the September landing, NASA conducted a series of rehearsals, spacecraft operations and sample curation with the **Lockheed Martin, the U.S. Defense Department and University of Arizona** to prepare. The material collected from Bennu will offer scientists a window into the time when the sun and planets were forming about 4.5 billion years ago. After dropping off the sample capsule, the OSIRIS-REx spacecraft was renamed **OSIRIS-APEX**. It fired its engines to leave Earth orbit and head toward a rendezvous with the near-Earth asteroid Apophis in 2029.

NASA's Jet Propulsion Laboratory began the final assembly, test and launch operations for the **Psyche** asteroid probe in June after completing a comprehensive test campaign of the flight software, clearing the hurdle that kept Psyche from making its original 2022 launch window. The spacecraft was launched from Florida in October. Psyche is one of the first missions of its type to study a metal-rich asteroid, not one made of rock and ice, orbiting the sun between Mars and Jupiter. Psyche's two 75-square-meter solar arrays collect the energy to produce electrical power at low illumination solar distances of approximately 3.35 astronomical units. Electric **Hall Effect thrusters** are propelling the spacecraft on its four-year journey to the asteroid. One of the firsts of the Psyche mission was a November test of a sophisticated new laser communication technology — the **Deep Space Optical Communications**, which encoded data in photons at near-infrared wavelengths to transmit data between the probe in deep space and Earth.

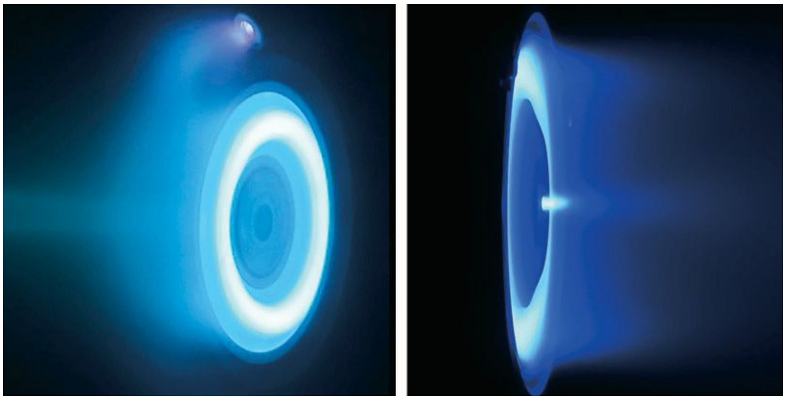
In August, the **Indian Space Research Organisation** landed its **Vikram** spacecraft near the lunar south pole. The mission, Chandrayaan-3, was ISRO's second moon landing attempt and the country's third lunar mission. Soon after landing, Vikram deployed its solar-powered rover, **Pragyan**, which traversed the lunar surface. The **Laser-Induced Breakdown Spectroscopy** instrument onboard the rover preliminarily confirmed the presence of **sulfur and metals** on the surface, according to an ISRO statement in late August, with additional measurements showing the presence of **manganese, silicon and oxygen.**

India is the fourth country to land a spacecraft on the moon. Previous unsuccessful attempts include India's Chandrayaan-2 in 2019 and Japan company **ispace** in April, whose **HAKUTO-R** lander ran out of fuel during its descent and crashed. Underscoring the difficulty: Russia's **Luna 25** lander crashed into the moon in August during its attempted landing, just days before the Chandrayaan-3 landing. ★

A year of firsts for electric propulsion

BY DAVID Y. OH AND PATRICK NEUMANN

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



▲ On the left is a Hall thruster identical to those installed on NASA's Psyche asteroid probe. On the right is a SpaceX argon Hall thruster operating at the company's vacuum facility in Redmond, Washington. This design is installed on the company's Starlink v2 Minis, the first of which were launched in February.

NASA/JPL-Caltech and SpaceX

In November, operators at **NASA's Jet Propulsion Laboratory** fired the **Hall Effect thrusters, or HETs**, on the **Psyche** spacecraft, the first time HETs have been used in interplanetary space. Built at JPL, Psyche was launched in October from NASA's Kennedy Space Center in Florida.

In February, **SpaceX** launched the first of its **Starlink V2 Mini satellites**. These next-generation spacecraft are equipped with HETs that operate on argon, instead of the krypton propellant on previous Starlinks. Shortly after launch, the satellites turned on their 4.2-kilowatt thrusters, the first time **argon HETs** have been operated in space.

In May, the 100th **BHT-350 HET** built by Massachusetts-based **Busek** was sent to orbit during a launch of 16 **OneWeb** satellites. Over 100 units are now operating in space aboard spacecraft in OneWeb's Gen1 broadband constellation.

In other satellite news, the **Gravity Space-1** satellite in August maneuvered to geostationary orbit via thrust vectoring with Austria-based Enpulsion's **NANO AR3** electric thruster. In June, **ExoTerra** of Colorado demonstrated its Halo micro-HET in orbit. In March, the water resistojet system built by **Pale Blue Inc.** of Japan was operated for the first time on the **EYE nano satellite** as part of the **STAR SPHERE project** by Sony Corp. In June, **Neumann Space** of South Australia launched the first center-triggered pulsed cathodic arc thruster.

In ground-based research, researchers from **Imperial College London, URA Thrusters** of the U.K. and **Aliena Pte Ltd.** of Singapore for the first time operated a HET with water electrolyzed into hydrogen for the cathode and oxygen for the main thruster. **University of Michigan researchers** demonstrated a tenfold increase in power density for a HET operating at 45 kW on xenon and alternative propellants. Under **NASA's Evolutionary Xenon Thruster project**, thrust levels of a gridded-ion thruster were doubled by incorporating modifications to increase beam uniformity in the thruster.

At the **Jet Propulsion Lab**, researchers developed a heaterless hollow cathode made of lanthanum hexaboride (LaB6) that radiatively heats the thermionic insert with a high-voltage discharge to an internal refractory metal tube. This technology eliminates arcing and has been used to reliably start LaB6 cathodes capable of discharge currents up to 50-300 amperes. In March, an **air-breathing microwave plasma cathode** was tested at the **University of Surrey** with a low-power xenon cylindrical HET. Researchers observed stable thruster operation on both xenon and air at thruster discharge powers of 100-300 watts.

In Massachusetts in January and May, students from **Olin College, Wellesley College** and **Brandeis University** fired a Hall thruster at 200-600 W, the first fully undergraduate team to design and operate a steady-state electric propulsion thruster.

Looking to future flights, **Northrop Grumman** in June secured orders for the last of three planned **Mission Extension Pods**. These all-electric "jet packs" would attach to satellites in geostationary orbit and maneuver them via **NGHT-1X** thrusters to extend their lifetimes. At Safran, the **PPS 5000** 5-kW HET saw a sharp increase in orders and production rates. Busek delivered the first two **BET-MAX** electrospray systems for launch.

In October, the **Japan Aerospace Exploration Agency, JAXA,** completed testing of its 6-kW-class HET. A unit is scheduled to launch in 2025 aboard Engineering Test Satellite-9.

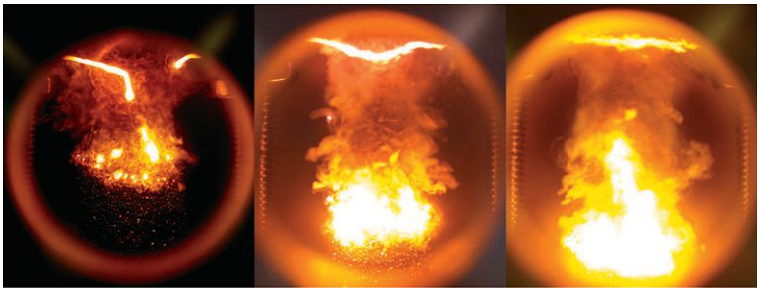
Qualification and production of flight hardware began for the first element of NASA's planned **Lunar Gateway** space station, the **Power and Propulsion Element**. Provided by **Maxar**, the PPE will have 48 kW of electric propulsion distributed among HETs provided by **Aerojet Rocketdyne** and **Busek**. In June, the second 13-kW integrated string test was completed at **NASA's Glenn Research Center** in Ohio, and Aerojet Rocketdyne and NASA in July completed acceptance testing of the first 12-kW Hall thruster.

Overall, the future looks bright with electric propulsion continuing to expand across the solar system. ★

University experiments lead to breakthroughs in combustion, development of customized propellants

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.



▲ Texas Tech University researchers created a metal-inorganic compound that can speed up combustion of a propellant. This burn rate modifier was combined with samples of nitroglycerin and nitrocellulose, shown here burning at pressures of 500, 1,000 and 1,500 pounds per square inch (from left to right). High pressures are representative of rocket motor operating conditions.

Texas Tech University

To burn **solid propellants** more quickly, propulsion engineers often turn to **burn rate modifiers**, chemical compounds that speed up combustion. However, conceptual roadblocks remain in describing how these burn rate modifiers control combustion. In June, researchers from **Texas Tech University** tackled the problem by designing a material intentionally packed with all the properties predicted to play a role in modifying propellant burn rates. The new material is called a **metal-inorganic-framework**, or MIF. The molecular structure of a MIF resembles a metal-organic framework, except the linker molecule is inorganic and the whole compound is oxidizer rich. With the MIF powder, researchers tailored propellant burn rates with new intuition — one that takes specific aim at the confusion between material properties and their functional relationship with combustion performance. Key properties include a targeted decomposition energy threshold, high porosity, surface chemistry to trigger catalysis and metal cations that incite exothermicity. They published their breakthroughs in August in the journal **Advanced Engineering Materials.**

In February, researchers from **Purdue University** in Indiana and the **Lawrence Livermore National Laboratory** in California published an editorial in the journal **Propellants, Explosives, and Pyrotechnics**. The focus was on embracing anisotropy in energetic materials made via advanced and traditional manufacturing methods. In the editorial, the researchers issued a call to industry to develop new diagnostic and analysis techniques to assess anisotropic properties of next-generation propellants. In this vein, researchers from **Purdue University's Zucrow Laboratories** presented their new technique for measuring the adhesion between dissimilar polymer materials at the **AIAA SciTech Forum** in January. In their experiments, adhesion between 3D-printed thermoplastics and hydroxyl-terminated polybutadiene was quantified for the first time. Quantifying interfacial properties as a function of material and manufacturing techniques could provide new data for assessing anisotropy in new energetic systems.

In June, the **University of Minnesota's Plasma Power Propulsion Laboratory** began a partnership with the **U.S. Army Research Laboratory** to expand the **laser-induced air shock from energetic materials, or LASEM, technique** for customized propellant development. LASEM assesses shock velocity generated by a high-energy laser pulse on small solid fuel samples to evaluate novel tailored propellants. Nanoenergetic materials are crucial for propulsion due to their high-energy density and faster burn rates, which surpass conventional propellants such as hydroxyl-terminated polybutadiene. The Minnesota lab applied a physics-driven approach to tailor coat nano aluminum particles by exploring the fundamental multistage complex combustion dynamics. When exposed to a high-energy laser pulse, the aluminum nanoparticles vaporized and underwent a two-stage combustion process. The initial microsecond combustion phase enhanced laser-induced shock speed, potentially correlating with detonation velocities of nanoparticles. In the subsequent millisecond phase, ejected materials underwent solid-phase combustion, allowing for the exploration of heterogeneous aspects of metal nanoparticle combustion. Because shock velocity is influenced by propellant reactivity, that factor is a valuable tool for the rapid development of highly reactive propellants. With the LASEM technique, the researchers conducted cost-effective testing of new propellant formulations with milligram- to gram-sized samples, eliminating the need for expensive testing with kilogram-sized samples. ★

Contributors: *Sayan Biswas, Mitch Donoughue, Monique McClain, Michelle Pantoya and Binit Singh*

Gas turbine engines gear up for advanced architectures and measurements

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 and Whitney of Connecticut in January announced that its family of **Geared Turbofan engines** has saved over a billion gallons of fuel and reduced carbon emissions by 10 million metric tons since their introduction in 2016. The geared fan enables the rotating turbomachinery to operate more efficiently at different speeds, reducing fuel burn and noise. Pratt and Whitney has continued testing the operation of the GTF engines on **sustainable aviation fuel**. The GTF engines produce up to 151 kilonewtons (34,000 pounds of force) of thrust and power aircraft including the Airbus A320neo.

In February, **Pratt and Whitney Canada**, headquartered in Quebec, reached a billion flight hours over its 95-year history. In a press release, the company said it has produced "more than 110,000 engines" across a range of aircraft markets. The **PT6** turboprop and turboshaft engine family accounted for 500 million of the flight hours, with upwards of 64,000 engines produced in its 60-year history.

Rolls-Royce of the U.K. announced in May that it tested its **UltraFan** engine demonstrator with 100% **sustainable aviation fuel** in its Derby, U.K., test facility. The UltraFan engine features the largest fan in the industry at 3.56 meters (140 inches), with a geared design unique to this size of engine and tested scalable technologies for 111-490 kilonewtons (25,000-110,000 pounds of force) thrust engines. The design is Rolls-Royce's first new engine architecture in 54 years, and the company says the geared fan design is scalable to a range of architectures for narrow and widebody aircraft. Rolls is targeting a 10% efficiency improvement over its **Trent XWB** engines.

GE Aerospace of Ohio announced in June that it was evaluating **open-fan engine concepts** with the U.S. Department of Energy's **Frontier supercomputer** at **Oak Ridge National Laboratory** in Tennessee. GE's simulation of air flow and acoustics associated with the full-scale open-fan design required new computational fluid dynamics software capable of executing on the world's fastest supercomputer, a Cray EX-based system capable of 1.6 exaflops (1.6x1018 floating-point operations per second). Application of advanced and large-scale computing in the design process offered unprecedented levels of physics detail and will be instrumental in meeting industry goals for net-zero carbon emissions by 2050. The open-fan engine architecture increases efficiency by removing the nacelle. CFM International is also studying this configuration under its **Revolutionary Innovation for Sustainable Engines, RISE,** program, and plans call for ground and flight tests in the mid-2020s. The goal is to reduce carbon dioxide emissions by 20% compared to today's engines. CFM International, a joint venture of **GE Aerospace** and **Safran Aircraft Engines** of France, produces **CFM56** engines as well as **Leading Edge Aviation Propulsion** engines, which reached 25 million flight hours late last year.

In August, **GE Aerospace** announced that its GEnx family of engines reached 50 million flight hours since its introduction in 2011. GEnx variants power the **Boeing 787 Dreamliner** and **747-8**.

In June, **Pratt and Whitney** and **Virginia Tech** announced a partnership to test a **laser-based measurement method** for thrust and emissions on a static engine test. The **Filtered Rayleigh Scattering for Thrust** technique measures velocity, temperature and density via nonintrusive lasers and cameras rather than sensors and probes. The technique captures the interaction of light and particles in the exhaust gases of an engine to simultaneously quantify multiple parameters. The laser-based FRST measurements are less intrusive in space-limited applications and are cost-effective for development of more efficient gas turbine engines with fewer pollutants. ★

▼ Rolls-Royce announced in May that it powered its UltraFan demonstrator on 100% sustainable aviation fuel for the first time. The fuel, provided by Air BP, was derived from used cooking oil and other waste-based feedstocks.

Rolls-Royce

Accelerating toward hypersonic civilian flight

BY BAYINDIR H. SARACOGLU, FRIEDOLIN STRAUSS AND JESSE S. KADOSH

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.

▲ Boom Supersonic conducted taxi tests this year with its XB-1 demonstrator in preparation for its first flight. As of November, the company had not announced a date for that flight of the one-third-scale aircraft that will test technologies for the Overture supersonic airliners that Boom plans to sell.

Boom Supersonic

This year was exciting for **high-speed air-breathing propulsion, HSABP**. In May, the hydrogen/oxygen air vitiator facility at test bench **M11.1** at the **German Aerospace Center, or DLR**, in Lampoldshausen was readied for upcoming **hydrocarbon-based liquid fuel tests** for the MORE&LESS, or **Multidisciplinary Design Optimization and Regulations for Low-Boom and Environmentally Sustainable Supersonic Aviation project**. The tests use biofuels and kerosene to test their pollutant generation, atmospheric impact and combustion processes. **DRL's Institute of Space Propulsion** operates the test bench, which is capable of simulating combustion chamber inlet conditions at Mach 5.5 to Mach 8.

The facility also continued an **injector reference test campaign** for **MORE&LESS**, funded by the **European Union**, to address the technical challenges and legal framework for sustainable supersonic flight. Within the project, an extensive test campaign validated computational fluid dynamics simulations for various partners, including **Lund University** in Sweden, the **von Karman Institute for Fluid Dynamics** in Belgium and **Reaction Engines** of the U.K. Initial comparisons show good agreement between experimental and computational data. Additionally, throughout 2023, DLR carried out several internal test campaigns to address material testing for HSABP and injector development.

In June, the **European Space Agency** held a three-day innovative propulsion workshop to centralize academic and industrial efforts on advanced propulsion technologies, including hypersonic propulsion.

Also in June, Ohio-based **Velontra** announced the testing of **Bronco**, a1.5-meter-long, 28-centimeter-diameter engine suited for smaller hypersonic drones and air vehicles. The Bronco design utilizes a Velontra-developed **afterburner** and a **ramjet** to accelerate to hypersonic speeds. Velontra tested the combination engine early in the year at the **Filtered Rayleigh Scattering for ThrustHigh-Pressure Combustion Laboratory** in Indiana. Velontra CEO Robert Keane III said that Bronco was tested "at speeds over Mach 4.5 and altitude simulated over 100,000 feet, and it successfully screamed through vigorous testing with flying colors." The company last year signed a contract to provide four Broncos to Venus Aerospace of Texas for testing Venus' planned Stargazer hypersonic passenger aircraft.

In Alberta, Canada, **Space Engine Systems** ground tested its **DASS GNX** engine in turbojet and ramjet modes in preparation for installation into the Hello-1X demonstrator. Currently under construction, the Hello-1X is being designed for point-to-point, suborbital and low-Earth orbit missions with payloads up to 550 kilograms. The campaign was conducted in the company's first mobile **turbo-ramjet test cell**, which can withstand up to 111 kilonewtons of force. Space Engine Systems used multiple fuels, including **Jet A** and **hydrogen**, with a 3D-printed gyroid **hydrogen precooler**. Precooler materials mainly consisted of Inconel 718 and titanium, with various internal coatings to mitigate hydrogen embrittlement at high temperatures. Assessment included heat exchanger expansion and stress at simulated altitudes from sea level to 30 kilometers and speeds up to Mach 5.

In August, **Boom Supersonic** announced the receipt of an **FAA Special Airworthiness Certificate** for its **XB-1** subscale demonstrator. The aircraft was moved from Boom's Colorado facilities to the **Mojave Air and Space Port** in California in preparation for its inaugural flight. Boom Supersonic has agreements with airspace authorities to facilitate flights over the Mojave Desert, the iconic airspace where Chuck Yeager broke the sound barrier in the **Bell X-1** and the **SR-71 Blackbird** made its first flight in 1964. The XB-1 has a 20-meter carbon composite and titanium fuselage and is propelled by three **General Electric J85 engines**, producing a combined thrust of 55 kilonewtons.

Also this year, the **Japan Aerospace Exploration Agency, JAXA,** performed post-flight analysis on a Mach 8-plus integrated scramjet vehicle model it tested in its **High Enthalpy Shock Tunnel,** and continued post-flight analysis of the **RD1** supersonic combustion flight test conducted in July 2022. ★

Contributors: *Joel Malo de Molina, Khaled Sallam and Hideyuki Tanno*

New hybrid rockets prepare for inaugural flights

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 was a year characterized by remarkable advancements in hybrid rocket technology across the globe. New space ventures and research institutions pushed boundaries while achieving significant milestones and propelling the industry forward.

German startup **HyImpulse** drew attention with the qualification tests of its **HyPLOX75** hybrid rocket engine. Powered by **paraffin and liquid oxygen**, this engine has a 30-second burn duration and 75 kilonewtons of thrust. In August, the engine passed two vital **qualification tests**, verifying that the technology is ready to power the **SR75** sounding rocket. The SR75 was designed as a suborbital technology demonstrator that would host microgravity payloads. HyImpulse plans to conduct the inaugural launch of an SR75 in early 2024. The company said in November that the inaugural launch would be conducted from Australia, but plans call for at least two future launches from the United Kingdom. In July, the **U.K. Civil Aviation Authority** granted HyImpulse a license to launch an SR75 from **SaxaVord Spaceport** in the Shetland Islands.

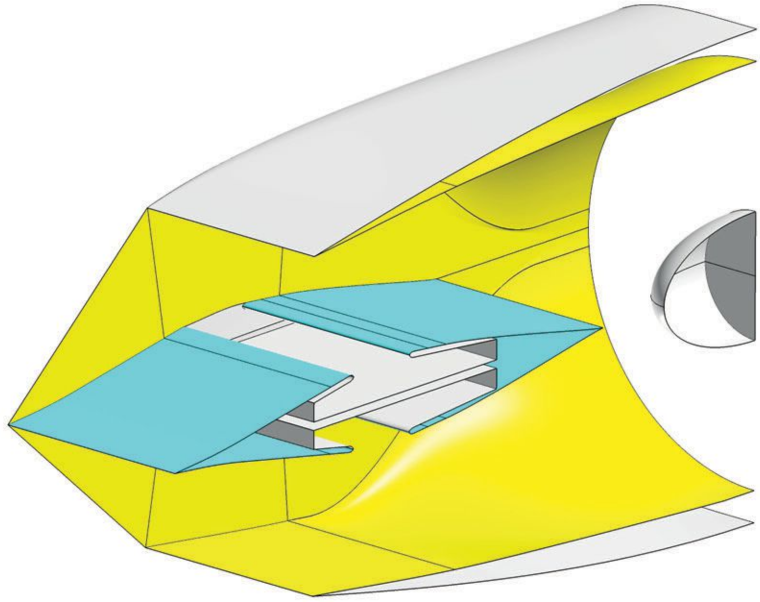
In Australia, **Gilmour Space Technologies** prepared for the inaugural launch of its hybrid-powered **Eris** orbital rocket, fueled by the 120-kilonewton **Sirius** hybrid rocket engine. That launch is scheduled to occur from a private site in northern Queensland. The Sirius engine, which completed flight qualification testing last year, is to propel both the first and second stages of the Eris. A **Phoenix** liquid-propellant engine is to power the third stage. During the unveiling of the Eris at Gilmour's production facility in May, **Australian Prime Minister Anthony Albanese** hailed the rocket as the nation's first domestically produced orbital launch vehicle. Pending regulatory approvals, Gilmour is targeting a launch window that would open in December from the **Bowen Orbital Spaceport**, Australia's commercial orbital launch site.

Taiwan's **National Cheng Kung University**, specifically the **Satellite and Rocket Propulsion Laboratory**, also contributed significantly to global advancements in hybrid rocket technology. Building on their past experience, researchers are targeting late this year or early 2024 for the inaugural launch of a 10.5-meter-tall sounding rocket with a 29-kilonewton thrust first-stage engine and a 14-kilonewton thrust second stage engine. Each engine is to be fueled by a **hydroxyl-terminated polybutadiene, paraffin and nitrous oxide** propellant. Anticipated to weigh around 700 kilograms, this rocket is projected to reach an altitude of 80 kilometers while carrying up to 50 kilograms of suborbital science experiments. To prepare for the inaugural launch, SRPL researchers developed and launched pilot sounding rockets in 2019 and 2022 to validate their two-stage rocket technology.

These milestones demonstrate the breadth of innovation and dedication underlying the field of hybrid rocket technology as well as the continued efforts and ingenuity of engineers driving the field forward. If all goes as planned, we are on an exciting trajectory for the future of space exploration. ★

▼ HyImpulse of Germany fired its HyPLOX75 hybrid rocket motor in August. These qualification tests were in preparation for the inaugural launch of the company's SR75 sounding rocket, targeted for 2024.

HyImpulse Technologies



New design and analysis tools, plus collaboration on hydrogen fuel systems

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.

▲ This two-dimensional bifurcated inlet was designed via NASA's SUPIN Supersonic Inlet Design and Analysis Tool. NASA released a new version of the software in February.

NASA

In January, the sixth **AIAA Propulsion Aerodynamics Workshop** was held in conjunction with the **2023 SciTech Forum**. The objective was to assess the numerical prediction of current **computational fluid dynamics** technology for inlets, diffusers and nozzles and to develop practical guidelines for CFD prediction of propulsion flow fields. Advanced computational methods were applied to supersonic aircraft inlet and nozzle problems, consisting of **heated supersonic jet plumes** from axisymmetric convergent-divergent nozzles. Variations in jet Mach number and jet heating were considered. **Reynolds-averaged Navier-Stokes** and **large-eddy simulation** solutions were compared to nonintrusive velocity and temperature data. Standard RANS models were unable to accurately reproduce trends established experimentally in terms of mean velocities and temperatures, as well as turbulent statistics. LES techniques were able to reproduce these trends more accurately; however, capturing the initial part of the jet shear layer remains a challenge because the small turbulent scales in the **boundary layer** that feed the initial part of the jet are prohibitively expensive to capture. The workshop also focused on a Mach 3 mixed-compression inlet with a complex boundary layer bleed system and vortex generators to provide stable inlet operation. Only RANS approaches were able to provide a sufficient grid resolution and computational effort to model the complete inlet system. A **wall-modeled LES, or WMLES**, approach did not result in a started supersonic inlet state. While this technique has been increasingly applied in analysis of engineering flow problems, WMLES and other scale-resolving techniques still need research.

In February, **NASA** released a new version of the **Supersonic Inlet Design and Analysis Tool, NASA SUPIN-2023A**. The Fortran-based SUPIN tool performs design and analysis of axisymmetric pitot, three-dimensional pitot, axisymmetric-spike, two-dimensional and streamline-traced inlets for supersonic speeds of Mach 1.2 to 5. SUPIN produces inlet performance metrics and geometric data. The inlet performance metrics calculated include the flow rates, total pressure recovery and drag. SUPIN can create the surface grids for the inlets for visualizing inlet geometry, as well as generating volume grids for CFD simulations. SUPIN can also automatically generate three-dimensional, multiblock structured grids for CFD simulations. The latest release includes improved modeling of mixed-compression inlets and more options for output of inlet data.

In June, **GKN Aerospace** of the U.K. and **Embraer** of Brazil announced a collaboration agreement to explore the potential for a **hydrogen-powered flight demonstrator**. The companies plan to develop **hydrogen combustion and fuel cell technologies** and optimize airframe-propulsion integration. This work would be applied to **Embraer's Energia future aircraft project** in which the company aims to develop hybrid-electric and hydrogen fuel cell aircraft concepts as its contribution to the aviation industry's effort to reach net-zero carbon emissions by 2050.

In related news, in August, **GKN Aerospace**, **Marshall** of the U.K. and **Parker Aerospace** of Ohio announced a memorandum of understanding in which the companies will explore **liquid hydrogen propulsion** for a future generation of zero-emission aircraft. Plans call for a liquid hydrogen fuel system that could be incorporated into hydrogen-electric and liquid combustion aircraft. "In developing the system, the companies will combine their extensive experience in the design, testing, certification, and manufacture of novel fuel systems for aerospace applications," according to a GKN press release. The proposed liquid hydrogen fuel system is to be tested alongside a **hydrogen-electric fuel cell** that GKN is separately developing under the **H2GEAR program**, funded by the **U.K. Aerospace Technology Institute**. Plans call for ground tests with the fuel cell in 2025 in preparation for testing both technologies together in a "flight test bed environment" by 2030, according to the press release. ★

Contributor: *Nicholas J. Georgiadis*

New engine development on the rise, with liquid methane taking center stage

BY BRANDIE L. RHODES

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

▲The final Ariane 5 was launched in July from Kourou, French Guiana, carrying two communications satellites. Its successor, the Ariane 6, is targeted to make its inaugural flight in 2024.

ESA/CNES/Arianespace/Optique video du CSG/P. Piron

In July, an **Ariane 5** lifted off from the **Kourou Spaceport** in French Guiana for the 117th and final time. The expendable design was the guarantor of Europe's independent access to space for almost three decades. In preparation for the inaugural flight of an **Ariane 6**, scheduled for 2024, **ArianeGroup** fired the **Vulcain 2.1** engine at the Kourou launch complex. Also in September, engineers from the **German Aerospace Center, or DLR**, the **European Space Agency** and **ArianeGroup** completed hot fire testing of the Ariane upper stage, which includes the **Vinci** engine and an auxiliary power unit, at the DLR site in Lampoldshausen, Germany.

SpaceX's second fully stacked **Starship-Super Heavy** took to the skies in November. The flight ended early, but SpaceX achieved several objectives, including ignition of all engines and clearing the launch pad, plus booster and upper stage separation via a new **hot-staging technique,** in which the upper stage engines ignited while still connected to the booster. The Starship upper stage is powered by three gimballing, sea-level optimized engines and three fixed-vacuum-optimized full-flow staged-combustion-cycle engines, each powered by **liquid oxygen and liquid methane**.

In March, NASA selected **Blue Origin's National Team** to provide the second human landing system for the Artemis program. The lander, which will carry astronauts for the **Artemis V** mission scheduled for 2029, will be powered by the **BE-7**, a deep throttling **liquid oxygen/liquid hydrogen engine**. Starting with Artemis V, NASA's **Space Launch System** rockets will be powered by redesigned **Aerojet Rocketdyne RS-25** engines. The updated engines will have simplified component designs that take advantage of 3D printing and other manufacturing advances. In June, a series of certifications tests were completed at **NASA's Stennis Space Center** in Mississippi, in which an RS-25 was powered for eight minutes to represent how long the engines must operate during flight.

In June, **United Launch Alliance** test fired a **Vulcan Centaur** booster with two **Blue Origin BE-4** engines. Vulcan's inaugural flight, scheduled for December, will also be the first flight of these liquid oxygen and liquid methane engines.

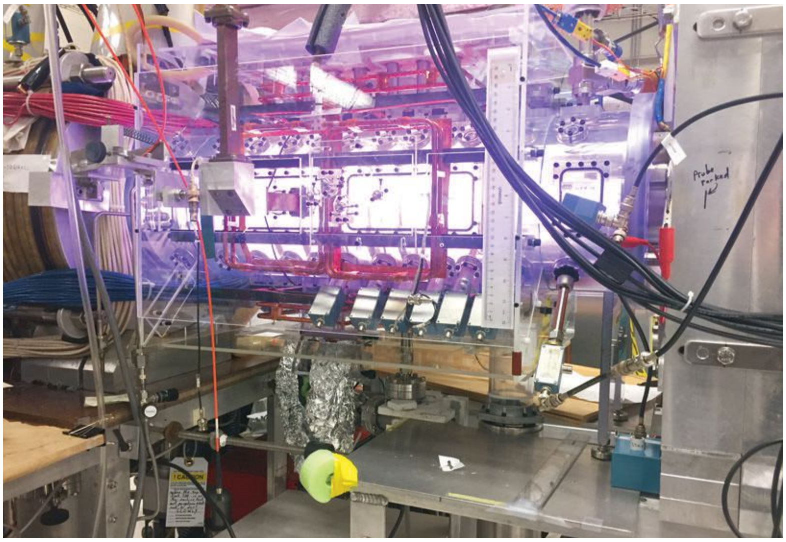
In July, **Sierra Space** of Colorado won an **U.S. Air Force contract** of $22.6 million to continue the maturation of its **VR35K-A** advanced upper stage engine. The VR35K-A is a liquid oxygen/liquid hydrogen staged combustion cycle engine that produces 140 kilonewtons of thrust. The engine has a single-shaft turbo-pump assembly for simplified operation and mechanically coupled mixture ratio control.

In February, **Dynetics** of Alabama completed a full-scale combustion chamber test of its 35-kilonewton **dual expander main engine** at **NASA's Marshall Space Flight Center** in Alabama and vacuum testing of its **dual mode reaction control system thrusters.** Dynetics further matured the technologies this year under a NASA Human Landing Systems Next Space Technologies for Exploration Partnerships-2 Appendix N contract.

German startup and launch service provider **Rocket Factory Augsburg** completed a full-duration hot-fire test of its **Helix** engine in June. This was the first time that a privately developed staged combustion upper stage had been successfully hot fired in Europe. **The Exploration Co.**, another German space startup, tested its reusable and throttleable orbital bio-methane and oxygen full-scale thrust chamber on the **P8** test bench in Lampoldshausen in July.

Liquid oxygen/liquid methane engine development also progressed in Italy and France. **ArianeGroup** completed the first test of the **Prometheus** engine in June, with a 12-second burn while integrated to the **Themis** first-stage demonstrator. **Avio** of Italy completed the first test of the **M10/DM2** engine in August at the new **Space Propulsion Test Facility** in Sardinia. Also, in March, the Italian government awarded a 103.7-million-euro contract to Avio, initiating the development of an additional engine called HTE. ★

Contributors: *Nathan Andrews, Colin Cowles, Christoph Kirchberger, Anne Lekeux, Scott Miller, Francesco Nasuti, Ken Philippart, Chip Sauer and Steve Shark*



Space nuclear propulsion collaborations prepare to take flight

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.

BY BRYAN PALASZEWSKI, STEPHANIE THOMAS AND KURT POLZIN

In January, **NASA Administrator Bill Nelson** announced a collaboration with **DARPA** on a nuclear thermal rocket. The exhaust velocity of **nuclear thermal propulsion, or NTP**, is approximately twice that of the best conventional chemical rocket engines, which could reduce the transit time of long-duration flights to destinations including Mars. Under the DRACO program, short for **Demonstration Rocket for Agile Cislunar Operations**, NASA will lead development of an engine in which liquid hydrogen will be heated by a reactor to propel the spacecraft. In July, DARPA announced **Lockheed Martin** would design and build the demonstration spacecraft, with Virginia-based **BWX Technologies** developing and fabricating the nuclear reactor. Plans call for an in-space demonstration by 2027, in which a conventional rocket would launch the DRACO spacecraft to a high orbit before the reactor is activated. This high altitude minimizes the risk of the spacecraft entering the atmosphere. Also, the reactor is to be fueled with **high-assay low-enriched uranium**, which contains lower levels of the uranium 235 isotope than weapons-grade uranium.

▲ Scientists at Princeton Satellite Systems and the Princeton Plasma Physics Laboratory in New Jersey this year tested a fusion reactor configuration for a planned dual-use fusion reactor. In this method, hydrogen plasma is heated and confined via rotating magnetic fields. In space, the reactor would operate in direct drive mode and propel a spacecraft to high speeds for interplanetary missions.

Princeton Satellite Systems

NASA also continued to mature NTP components and systems through its **Space Nuclear Propulsion project**. Development and testing continued of ceramic-metallic, ceramic-ceramic, solid-solution nuclear fuels and other materials for nuclear reactors at **NASA's Marshall Space Flight Center** in Alabama, **NASA's Glenn Research Center** in Ohio, various **U.S. Department of Energy** national laboratories and the **MIT nuclear reactor facility**. NASA and the Department of Energy awarded California-based **General Atomics** and **Ultra Safe Nuclear Corp.** of Washington additional funding for NTP reactor concepts, work that began under initial contracts awarded in 2021. The extensions are to fund activities including manufacturing demonstrations and hardware test and evaluation, targeted for late this year and early 2024.

Also under the Space Nuclear Propulsion project, Virginia-based **Analytical Mechanics Associates** in January analyzed **megawatt radiators** for nuclear electric propulsion. These winglike structures collect heat from reactors and direct that heat into space. No fission or fusion engine is 100% efficient, meaning there will always be waste heat to control. The radiator modeling included numerous parameters and analyzed designs larger and more powerful than 100 kilowatts, which will be required for large nuclear-powered spacecraft planned to transport cargo and humans to deep space.

In September, the **Air Force Research Laboratory** awarded three contracts under its **Joint Emergent Technology Supplying On-Orbit Nuclear Power, or JETSON**, project, which aims to build a prototype of a fission reactor that could power a spacecraft in an in-flight demonstration. **Intuitive Machines** of Texas received $9.4 million to design a spacecraft with a "radioisotope power system, electric and/or hybrid propulsion," according to a Defense Department contract announcement. **Lockheed Martin** received $33.7 million to mature the design of a JETSON spacecraft and "fully develop the overall program development and test program planning through critical design review." **Westinghouse Government Services** of South Carolina received $16.9 million to study how a fission reactor "could be implemented from a subsystem, spacecraft, and architecture standpoint."

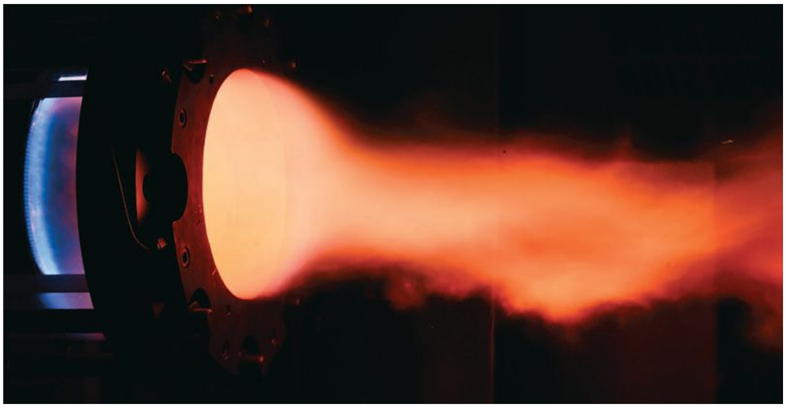
In June, **Princeton Satellite Systems** of New Jersey and U.K. propulsion company **Pulsar Fusion** announced a collaboration to apply machine learning to the **Princeton-field reversed configuration experiment** at the Princeton Plasma Physics Laboratory, the basis for Princeton Satellite Systems' **Direct Fusion Drive rocket** and reactor concept. Researchers will analyze stabilization methods of the plasma under electromagnetic heating and confinement as relevant to future aneutronic fusion propulsion. In the proposed design, a nuclear reactor would fuse hydrogen and helium atoms, generating energy that heats a hydrogen propellant to create thrust. The researchers estimate this fusion engine would generate exhaust with a velocity between 10 to 100 times greater than conventional chemical rocket engines. Princeton Satellite Systems has been developing this technology with the laboratory since 2011. ★

Advancements continue in rotating detonation engines

BY SHIKHA REDHAL AND JASON R. BURR

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.

In response to growing government demand for enhanced combustor efficiency and the aerospace sector's quest for improved performance with reduced combustor weight and volume, research into **rotating detonation engine, or RDE**, technology saw significant research and development efforts this year across academic and commercial institutions. In June, the **European Space Agency** organized a three-day workshop aimed at consolidating academic and commercial initiatives focused on technologies for advanced propulsion applications, including RDEs, and to build a cohesive research road map for the European Union.



▲ Purdue University researchers this year test fired an annular rotating detonation rocket engine powered by natural gas and gaseous oxygen propellant at Maurice J. Zucrow Laboratories in Indiana. With this optically accessible combustor body, they visualized mode changes in the detonation behavior as combustor geometry was varied.

Carson Slabaugh/Purdue University

Under the **U.S. Department of Energy's University Turbine Systems Research program**, **Purdue University** in Indiana and **Argonne National Laboratory** in Illinois developed a **hydrogen-air RDE** with innovative nozzle guide vanes for power generation. Research throughout the year involved assessing combustor losses through a combination of laser diagnostics and numerical models, including large- eddy simulations and unsteady Reynolds-averaged Navier-Stokes, as well as utilizing reduced-order models. Plans call for retrofitting a **Rolls-Royce M250 engine** with a **hydrogen-powered RDE** in 2024.

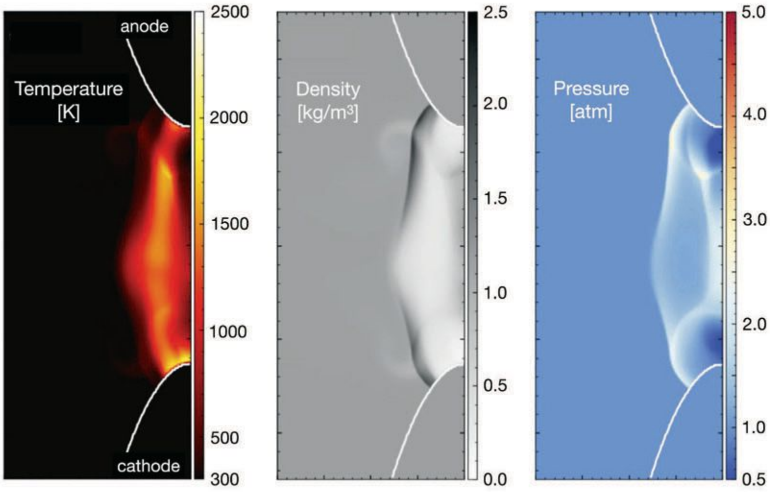
Optical diagnostic techniques played a pivotal role in driving rapid advancements of RDE technology. In March, researchers from the **U.S. Air Force Research Laboratory, Argonne National Lab and University of Alabama in Huntsville** characterized monodisperse droplet breakup and burning in Argonne's **Advanced Photon Source X-ray facility**. They imaged shock and detonation interactions for rocket-grade kerosene and water at 5 million frames per second at a scale of 30 to 200 micrometers, revealing complicated breakup physics. In February, Ohio-based **Spectral Energies** and **Purdue University**, in collaboration with **NASA's Glenn Research Center** in Ohio, developed 2 Mfps **planar laser-induced fluorescence, or PLIF**, of fuel and hydroxyl radicals to study the transient liquid spray response from hydrogen-air rotating detonations, providing benchmark data for validating models. In May, this research team also applied megahertz-rate PLIF in variably premixed hydrogen-air and natural gas-oxygen rocket RDE to assess parasitic deflagration for a wide range of operating conditions. The optical RDE platforms and tenfold improvement in measurement speed represent a new capability for physics-based understanding of rotating detonations.

In July, a **University of Michigan** computational research team developed a **state-to-state RDE model** to identify loss mechanisms. The team applied machine learning algorithms to estimate various performance parameters. To assess how geometry influences RDE injector performance, the Michigan researchers investigated a series of combustor channel shape and inlet area ratios between late 2022 and early 2023. They quantified the degree of blockages at the inlet relative to the mean operating conditions and identified a limiting behavior for the dependence on inlet blockage ratio to mean mass flow rate. They also performed particle tracking velocimetry to quantify the azimuthal flow swirl at the inlet and outlet of the RDE. They observed that coupling between the oxidizer inlet and the detonation wave induces secondary azimuthal flow that affects the propagation and properties of the detonation wave.

In space propulsion, in Japan, **Nagoya University, the Muroran Institute of Technology, Keio University and the Japan Aerospace Exploration Agency** in May operated a laboratory-scale **ethanol-nitrous oxide RDE** for rockets. In July, the prototype flight model was completed, and plans call for launching it aboard a sounding rocket in July 2024. In September, **NASA's Marshall Space Flight Center** in Alabama, with partners **Venus Aerospace of Texas, NASA Glenn and the Air Force Research Laboratory** fired a 2-inch water-cooled RDE, gathering scalability data for Venus' planned hypersonic aircraft engine technology demonstrator.

In August, a dataset of a **model detonation combustor** was published in the journal Scientific Reports. This work, conducted under the **AIAA Model Validation for Propulsion**, is part of an ongoing initiative to standardize experimental and computational procedures and analysis techniques. ★

Contributors: *Venkat Athmanathan, Eric Bach and John W. Bennewitz*



Advances in simulations and experimentation for clean and high-speed combustion systems

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.

▲ In this numerical simulation by researchers at the University of Texas at Austin, a filament of hot gases (left) was generated between two pin electrodes following a second nanosecond high-voltage pulse that deposited about 0.8 megajoules of energy in the air. Energy deposition occurred at a constant density during the first 100 nanoseconds, forming a pressurized channel that expanded (center) and generated a shock system (right) over 1-10 microseconds.

Fabrizio Bisetti/University of Texas at Austin

Increasing demand for wider operational envelopes and cleaner performance of modern engines requires advanced computational simulations and novel experimental methods. Combustion and propulsion systems researchers made significant contributions this year toward reaching that goal.

Understanding the behavior of **hydrogen-enriched hydrocarbon fuels** is a critical intermediate step in developing zero-carbon, pure hydrogen combustors. In July, researchers at the **University of Cincinnati** and the **U.S. Army Research Laboratory** published their findings on the effect of **isotropic turbulence** on premixed high-hydrogen content syngas and air flames in the journal Physics of Fluids. Via numerical simulations, they demonstrated that a laminar flame thickens as it interacts with a homogeneous isotropic turbulence field. What was unusual was that the flame thickened in the burnout zone rather than in the preheat zone, as observed in previous studies.

An **ignition assistant** is critical for small intermittent combustion engines to achieve reliable ignition of jet fuels in high-altitude conditions. One practical consideration is the IA durability due to high thermal fatigue and surface erosion. **Army Research Laboratory** researchers investigated the physics of spray interaction with superheated surfaces. In the first half of 2023, a **computational framework** was developed that accounted for heat transfer, atomization and dispersion of fuel droplets due to film boiling occurring on the IA surface. Subsequently, the framework was validated for a wide range of conditions using the experimental data obtained in a rapid compression machine.

Reliable technology for ignition in challenging conditions, such as ultra-lean fuel-air mixtures or high-speed reacting flows in scramjets, may be achieved by igniters based on **high-voltage nanosecond pulsed discharges** producing nonequilibrium plasmas. This year, a research group at the **University of Texas at Austin** developed a **high-performance computing framework** to simulate **plasma-assisted ignition** of fuel-air mixtures at realistic conditions. This framework, developed with funding from the **U.S. Energy Department** and **National Science Foundation**, combined an adaptive mesh refinement library, a plasma discharge solver and reactive flow solvers featuring physics-based high-fidelity models of the plasma and combustion kinetics, thermodynamic nonequilibrium gas expansion following isochoric energy deposition, and flame kernel development.

A team of researchers from the U.S. Air Force-funded **Center of Excellence on Multi-Fidelity Modeling of Rocket Combustor Dynamics** led by the **University of Michigan**, along with the **University of Texas at Austin**, **New York University** and the **University of Kansas**, made a breakthrough in fast and accurate predictions of **turbulent combustion dynamics**. With an **adaptive projection-based reduced order model**, they obtained an order of magnitude reduction in the cost of computing reacting flow in a single injector element rocket combustion chamber.

The next big leap in aerospace propulsion concerns **air-breathing propulsion at high hypersonic speeds** — Mach 8-17. One approach is the **shock-induced combustion ramjet, or shcramjet**, which compresses incoming air for combustion via obstacles such as wedges. From March to May, researchers at the **University of Minnesota** conducted computational fluid dynamics simulations to capture intricate details of the resulting **oblique detonation wave** stabilization process. The simulations revealed that ODWs possess a complex "zonal" structure, from mildly unstable detonations to locally hypersonic microjets, that helps to sustain ODW for consistent propulsion.

Methane-oxygen mixtures are becoming the combination of choice for high-performance reusable launch vehicles. **University of California at Los Angeles** and **Aerospace Corp.** researchers studied such mixtures in **shear-coaxial rocket injector designs** via a novel **infrared laser absorption tomography technique**. Their method enabled quantitative and spatially resolved carbon monoxide and temperature measurements via tomographic reconstruction within the near-field mixing region of various injector designs. They completed this work in June. ★

Contributors: *Fabio Bendana, Fabrizio Bisetti, Alex Keller, Prashant Khare, Mike Kweon, Ramakanth Munipalli, Mitchell Spearrin and Suo Yang*

Solid rocket boosters enable solid progress in space exploration

BY CLYDE E. CARR JR.

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

▲ A development motor based on one that will power the second stage of NASA's Mars Ascent Vehicle was tested in March at Northrop Grumman's facility in Elkton, Maryland. Part of the NASA-European Space Agency Mars Sample Return mission, the MAV would be the first rocket fired off another planet.

NASA

The year's top achievements in space would not have been possible without **solid rocket boosters**. These boosters were crucial to missions including cargo resupply, lunar exploration, satellite deployment, flight and static tests.

In terms of industry dynamics, propulsion maker **Aerojet Rocketdyne** in July was acquired by **L3 Harris**.

In the area of launch vehicles, **Japan** in January launched an **H-IIA** rocket, equipped with SRBs, placing the **IGS-Radar 7 satellite** into orbit. In September, another **H-IIA** was launched, carrying the **SLIM, Smart Lander for Investigating the Moon**. **China** was equally active, launching several SRB-based rockets throughout the year, including two three-stage **Kuaizhon-1A** rockets in January and July; and in April, a four-stage **Hyperbola-1**, a four-stage **Kinecta-1** and a three-stage **Gushenxing-1**. In July, the **Indian Space and Research Organization** launched a **Launch Vehicle Mark-4 M4** rocket equipped with two SRBs for its **Chandrayaan-3** moon mission. Those SRBs boosted the **Vikram lander** and **Pragyan rover** to orbit, setting up their August landing on the lunar south pole. ISRO also conducted various satellite launches, further solidifying its role in space exploration. August also marked the final launch of an **Antares 230+**, featuring a **Northrop Grumman Castor 30 SRB** second stage, which sent a **Cygnus** spacecraft to orbit to dock with the **International Space Station**. And in July, the final **Ariane 5** was launched, carrying the **Syracuse 4B and Heinrich Hertz communications satellites** into orbit. Since its debut in 1996, the Ariane 5 design has been launched 117 times.

SRBs also played a large role in flight testing. In March, the **U.S. Missile Defense Agency** and the **U.S. Navy** conducted the **Flight Test Aegis Weapon System 31 Event 1a**, intercepting a medium-range ballistic missile target during its terminal phase with an Aerojet Rocketdyne solid-fueled **Standard Missile–6 Dual II** rocket. Later in October, two ballistic missile targets were intercepted by two multistaged solid-fueled **SM-3** missiles launched from the USS Levin at the Pacific Missile Range Facility in Hawaii. In April, the **U.S. Air Force and Navy** jointly launched an unarmed **Minuteman III** intercontinental ballistic missile from Vandenberg Space Force Base in California, showcasing a reliable and effective nuclear deterrent as the vehicle impacted near the Marshall Islands. May marked the fifth successful flight of the U.S. Navy's **AGM-88 G Advanced Anti-Radiation Guided Missile-Extended Range**, which detected and engaged a land-based emitter target. Also in May, a Lockheed Martin **PAC-3 Missile Segment Enhancement** interceptor was fired from a German-modified **M903** launcher at White Sands Missile Range in New Mexico, demonstrating missile and launcher compatibility. In June, the **U.S. Navy** launched an unarmed **Trident II D5** life-extension missile off the coast of southern California — the 190th successful flight of a Trident since 1989. In July, the **Air Force and Raytheon** live fired an **AIM-120D-3 Advanced Medium Range Air-to-Air Missile** from an F-16, completing developmental and operational testing of the design.

In May, **Northrop Grumman** completed the first static test of the **Sentinel stage-one SRB** in Promontory, Utah. In June, **Aerojet Rocketdyne** conducted the first static testing of an **eSR-19** advanced large solid rocket motor, a crucial component for the next generation of **Medium Range Ballistic Missile** targets. In July, **NASA** announced progress in testing the solid rocket motors for its **Mars Ascent Vehicle**, a rocket in development for the **Mars Sample Return** mission. **Northrop Grumman** static fired the motors for the MAV first stage at the Air Force Research Laboratory's California facility and the second stage motor at the company's Elkton, Maryland, facility.

These missions made possible by SRBs underscore the progress made in launch technology, and the missions still in development may expand our knowledge of the cosmos. The future of space exploration shines brighter than ever, with endless possibilities lurking along the horizon. ★

Contributors: *Joseph Majdalani and Wesly Rayn*

Cryogenic fuels in aviation

BY CHUMING WEI AND BHUPENDRA KHANDELWAL

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.

▲ ZeroAvia this year conducted multiple test flights with this retrofitted Dornier 228. For the inaugural flight in January, one of the plane's turboprop engines was replaced with the company's hydrogen-electric powertrain.
ZeroAvia

Decarbonizing the transportation sector necessitates alternatives comparable to conventional liquid fuels with zero or as low as possible carbon content. Cryogenic fuels like hydrogen and natural gas are possible solutions, a crucial consideration for these fuels is their high volumetric and gravimetric energy densities. Liquification is required to maximize the volumetric energy density. Cryogenic technology is also advancing its energy efficiency. **Linde** of Ireland, **Air Liquide** of France and **Chart Industries** of Georgia predict that the cryogenic equipment market will be a $400 billion industry by 2033.

This year, the aviation sector witnessed groundbreaking strides toward sustainable flight, with several companies leading the charge by retrofitting existing aircraft to run on hydrogen. California-based **ZeroAvia** flight tested a 19-seat aircraft in January. The aircraft took off from Cotswold Airport in the United Kingdom, one of its turboprop engines replaced by a combination of batteries and hydrogen fuel cells; the other engine used conventional kerosene. Batteries and hydrogen each contributed 50% to powering the aircraft's left side during its 10-minute journey. **Universal Hydrogen** of California has retrofitted an **ATR-72** and a **De Havilland Dash 8-300** with a similar aim. The Dash 8 set a record in March as the largest aircraft to take flight propelled by hydrogen fuel cells. In the United Kingdom, **Cranfield Aerospace Solutions** prepared to unveil its converted nine-seat **Britten-Norman** demonstrator.

Airbus continued **cryogenic hydrogen tank** development at its **Zero Emission Development Centre** in Bristol, U.K. Cryogenic fuel storage is pivotal to the company's plans to have a hydrogen-powered passenger airliner flying by 2035. Plans call for Airbus has ground tests and, starting in 2026, flight tests with the ZEROe demonstrator. Simultaneously, its **Advanced Superconducting and Cryogenic Experimental Powertrain Demonstrator initiative** is delving into the potential of superconducting materials and cryogenic temperatures in aircraft electrical propulsion systems.

In June, **GKN Aerospace** in the U.K. and **Embraer** announced a partnership to develop a hydrogen flight demonstrator powered by GKN's advanced **fuel cell** concept, which uses a cryogenically cooled electrical system for superior efficiency. Such advancements not only cater to aircraft in the 100-plus passenger segment but also open the door for potentially larger models.

In June, **Narendra Joshi** of the **SafeAvia Ltd.** consultancy presented the progress made and the need for cryogenic renewable natural gas-powered aviation in a panel session at the **American Society of Mechanical Engineers' Turbo Expo** in London. He said it is important to solve the immediate problem of sustainability in aviation and that **cryogenic renewable natural gas** is an immediate solution. He also pointed out that production and pricing of **sustainable aviation fue**l is not at par with industry demands and that some other sustainable option is needed. He also questioned the operational viability of cryogenic hydrogen.

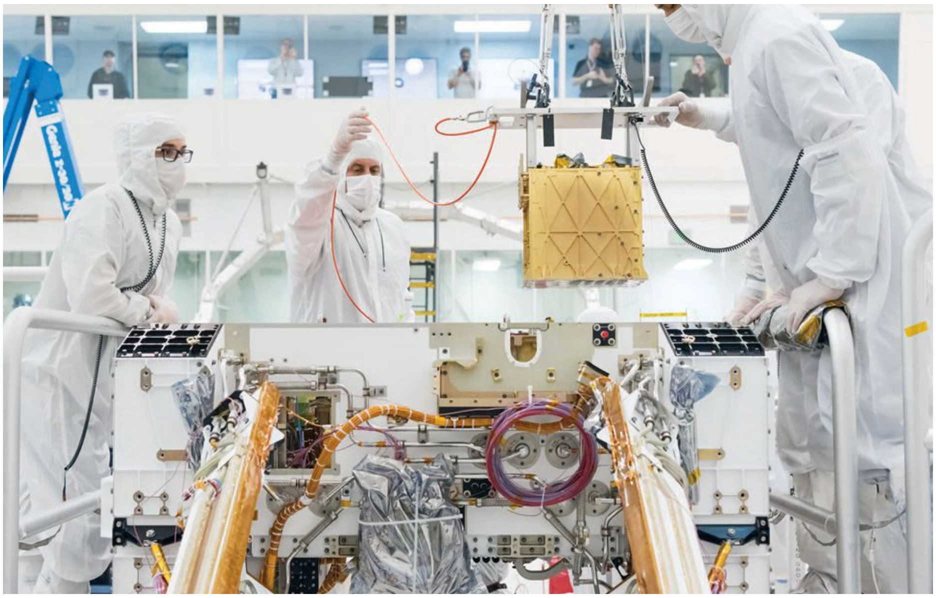
In July, phase one of the program **CHEETA, Center for High-Efficiency Electrical Technologies for Aircraft,** concluded. Funded by NASA and led by Phil Ansell from the **University of Illinois Urbana-Champaign**, researchers are studying cryogenic liquid hydrogen in collaboration with **Boeing**, **General Electric** and the **U.S. Air Force Research Laboratory**.

September saw the U.K.'s aviation giants — **easyJet**, **Rolls-Royce** and **Airbus** among them — form the **Hydrogen in Aviation alliance**. Advocating hydrogen as a key to decarbonize aviation, the alliance highlighted the work of its various members. Also in September, German company **H2FLY** reported the world's first piloted flight of an aircraft powered by **liquid hydrogen**. The company flew its **HY4** demonstrator from Maribor, Slovenia, powered by a hydrogen-electric fuel cell system using liquid hydrogen. ★

Extracting oxygen from Martian air and growing proteins, neurons in microgravity

BY JONATHAN METTS

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



▲ Technicians lower the MOXIE experiment (the golden cube) into the Perseverance rover in 2019 in preparation for the 2020 launch to Mars. From its location in Perseverance's chassis, the Mars Oxygen In-situ Resource Utilizated Experiment generated a combined 122 grams of oxygen over its two years of operation.

NASA/JPL-Caltech

NASA's **Mars Oxygen In-Situ Resource Utilization Experiment, MOXIE,** concluded operations in September after one full Martian year. Operating aboard the **Perseverance** rover, MOXIE doubled its nominal production rate of oxygen converted from the Martian atmosphere. The new record was achieved in June, when the instrument generated **12 grams of molecular oxygen** per hour during its 15th operational run. For comparison, one astronaut nominally consumes about 36 grams per hour. Over the course of the experiment, led by **MIT**, a combined 122 grams of oxygen was produced over 16 operational tests using the 100-Watt power budget from the Perseverance rover. MOXIE used **solid oxygen electrolysis** at 800 degrees Celsius to produce gaseous oxygen, a useful substance for propellant as well as life support, with byproducts including carbon monoxide and carbon residue. The Utah-based **OxEon Energy** team that provided the **Solid Oxide Electrolysis, SOXE, cell** for MOXIE is developing larger versions with increased duty cycles to study the viability of this technology for human Mars missions. The team tested SOXE prototypes scaled for exploration missions for thousands of operational hours, with results published in July showing peak oxygen generation of 28 kilograms per day in lunar conditions and 13 kg per day in a Martian atmosphere simulator at **NASA's Jet Propulsion Laboratory** in California.

In June, **Varda Space Industries** of California announced its small pharmaceutical satellite had produced crystals of **ritonavir**, an HIV drug. The spacecraft, **W-Series 1**, was lofted to orbit on a SpaceX rideshare launch and is designed for controlled reentry and subsequent payload retrieval. Multiple space agencies and major pharmaceutical companies have flown hundreds of similar experiments on the space shuttles and **International Space Station**, but Varda's approach leverages automation and availability of reusable launch vehicles to reduce the cost of such research. **Protein crystal growth in microgravity** results in larger, more uniform crystals that are easier to study and may have medical advantages compared to terrestrial crystals.

Boston-based **Axonis Therapeutics's Neuronix** system, launched aboard a **Northrop Grumman Cygnus** cargo spacecraft in July, uses three-dimensional formation of **neuron cells** to study neurodegenerative disease and the effectiveness of a gene therapy. ISS astronauts activated Neuronix in August. The neurons, grown from human stem cells, exhibited a 3D structure in microgravity, which is more anatomically correct than standard terrestrial cell cultures. The 3D structure helps researchers study the human stem cells and their response to a neuron-targeting gene therapy. Investigators aim to develop new treatments for paralysis and for neurological diseases like Alzheimer's, Parkinson's and Huntington's.

NASA's Johnson Space Center in Texas concluded its **Investigating Structure and Function of the Eye, or ISAFE, experiment,** aboard ISS in September. Vision and ocular health data was collected from astronauts after varying mission durations, up to one year in orbit. The study concerns whether spaceflight duration affects the onset and severity of **spaceflight-associated neurocular syndrome, SANS,** and whether vision returns to normal after returning to Earth gravity. Space medicine research has shown in recent years that the fluid shifts in microgravity, along with other factors yet to be determined, leads to degraded vision in most astronauts who spend at least a month in space. **NASA's Human Research Program** is studying SANS to develop mitigations and to better understand exploration risks. ★

Advancements in heat transfer research and a new platform for microgravity experiments

BY SUNIL CHINTALAPATI

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.

In March, researchers from **Rensselaer Polytechnic Institute** in New York, in collaboration with **Tec-Masters Inc.** of Alabama, sent an experiment to the **International Space Station**. The Microgravity Research for Versatile Investigations-Phase Change in Mixtures, or MaRVIn-PCIM, experiment focuses on how fluid mixtures, particularly liquid and vapor, influence the functionality of **wickless heat pipes** under the conditions of microgravity. The pipes were installed in the **Microgravity Science Glovebox** in August, where one end of a pipe is heated to evaporate a liquid while the other end is cooled to condense the vapor back. This allows the researchers to observe and map shifts in the vapor-liquid boundary. Drawing upon previous experiments, the researchers chose a 50/50 mixture of pentane and isohexane liquids. Results from this investigation may enhance the efficiency of heat pipes, which are integral to various space applications, including satellites, rovers and space telescopes, where maintaining optimal temperature levels is crucial. The results could also further the research and development of advanced, lightweight and efficient cooling mechanisms tailored for future space missions. On Earth, heat pipes are pivotal in thermal management of microelectronic components present in laptops, graphics cards, avionics, hypersonic systems and nuclear reactors.

▼ In February, Gravitilab Aerospace Services of the United Kingdom flew this drone from Predannack Airfield to demonstrate a more affordable way of conducting experiments in microgravity. The vehicle carried the company's LOUIS drop pod to an altitude of about 600 meters before releasing it.

Gravitilab Aerospace Services

In May, researchers from **Auburn University** in Alabama and the **University of California-Davis** published their findings from the Pore Formation and Mobility Investigation-Asymmetric Sawtooth and Cavity-Enhanced Nucleation-Driven Transport study. They demonstrated a passive cooling system for electronic devices in microgravity via a **microstructured surface**, meaning one textured like saw teeth. In microgravity, boiling fluids over flat, heated surfaces creates larger vapor bubbles due to the absence of buoyancy force, leading to inefficient heat transfer. This inefficiency can result in unpredictable surface temperature spikes, potentially damaging electronic devices. Sponsored by **NASA**, funded by the **National Science Foundation** and developed by **Techshot Inc.**, which Redwire Corp. of Florida acquired in 2021, a series of experiments were conducted between December 2022 and January 2023. Observations indicated that in microgravity, vapor bubbles rode on the crests of the saw teeth, whereas the baseline flat surface yielded stationary vapor bubbles that expanded in situ. The microstructure granted access to liquid pockets within the troughs for vapor bubbles upon reaching a specific mobility diameter, which enlarged with the elevation of heat input within the low heat flux range assessed. A comparable mobility was noted for the downward-facing terrestrial surface, with larger vapor slugs gliding over the microstructure in the direction of the extended slope. Conversely, the baseline surface yielded static vapor slugs that enveloped the entire heated region, devoid of a noticeable thin liquid layer. The identified vapor mobility could address a persistent microgravity issue, facilitating two-phase high-heat flux dispersion in electronic devices.

In February, **Gravitilab Aerospace Services Ltd.** conducted its first **microgravity experiment** aboard a drone at the **Predannack Airfield** testing site in Cornwall, United Kingdom. This facility offers an alternative to the **ZARM drop tower** in Bremen, Germany, which provides microgravity for between 4.74 and 9.3 seconds. Gravitilab's drone climbed to an altitude of 610 meters and then dropped an unspecified payload inside the company's LOUIS drop pod, providing microgravity for a handful of seconds. The test was commissioned by the **Cornwall and Isles of Scilly Local Enterprise Partnership** in an effort to enhance the U.K.'s space industry prominence. With the potential to provide gravity-free testing durations of up to 12 seconds, this technology has the potential to transform how a myriad of industries test. ★

The U.S. Army tested the first Long-Range Hypersonic Weapon in February. These ground-launched missiles have a hypersonic glide body and a reported range of 2,775 kilometers.
Spc. Chandler Coats/U.S. Army

Hypersonics continue to drive missile industry

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. continued to develop hypersonic weapons and defense technologies, following the 2022 Congressional Research Service report "Hypersonic Weapons: Background and Issues for Congress" and the success of various hypersonic programs. While high-profile efforts such as the **Air-Launched Rapid Response Weapon**, **Hypersonic Attack Cruise Missile** and **Hypersonic Air-breathing Weapon Concept** programs continued this year, additional activities gained the spotlight, such as the **Long-Range Hypersonic Weapon**, **More Opportunities with Hypersonic Air-breathing Weapon Concept** and **Hypersonic Air-Launched Offensive Anti-Surface Warfare**.

In March, the U.S. Air Force announced plans to conclude **ARRW, the Air-Launched Rapid Response Weapon** program, following several failed test flights with the Lockheed Martin-built prototypes, including one in March. The program is to end after an undisclosed number of additional test flights. One such test was conducted in August. The Air Force did not discuss its objectives or outcome, but said it gained valuable data to support other programs such as **Hypersonic Attack Cruise Missile, HACM**.

ARRW aside, **Lockheed Martin** continued to contribute to other programs such as the **Long-Range Hypersonic Weapon**. The U.S. Army intended to field the first LRHW by the end of September, pending delivery of the battery. In February, LRHW was deployed during **Thunderbolt Strike**, a full rehearsal of hypersonic launch capabilities.

In August, **Northrop Grumman** opened a new hypersonic propulsion systems manufacturing facility in Maryland. This **Hypersonics Capability Center** is the first U.S. facility designed specifically for large-scale manufacturing of **air-breathing propulsion**, including **ramjets** and **scramjets.** Scramjets for the Air Force's HACM are to be built there, but the facility has capacity to support additional future programs across the defense industry.

Northrop Grumman also continued its partnership with **RTX**, formerly Raytheon Technologies, for DARPA's **More Opportunities with Hypersonic Air-breathing Weapon Concept, MoHAWC**. This successor to the HAWC program was announced in July. RTX is also competing with Lockheed Martin under phase one contracts for the **Hypersonic Air-Launched Offensive Anti-Surface Warfare,** awarded by the U.S. Navy's Naval Air Systems Command in March. HALO is intended to meet the Navy's **Offensive Anti-Surface Warfare Increment 2** requirement and will be integrated on the Navy's **F/A-18E/F Super Hornets**. The **AGM-158C Long Range Anti-Ship Missile** meets the Increment 1 requirement.

In the academic world, the **University Consortium for Applied Hypersonics**, established in 2020, continued to enable collaboration between industry, government and academia for the Department of Defense's hypersonic efforts. In June, **Purdue University** opened its **Hypersonics and Applied Research Facility**, which houses two cutting-edge wind tunnels and the **Hypersonics Advanced Manufacturing Technology Center** — intended as a location for industry partners to conduct research and testing. In addition, the new Mach 8 quiet wind tunnel, the **hypersonic pulse tunnel**, can simulate speeds ranging from Mach 5 to Mach 40.

It is evident that hypersonic technology will remain a pillar of research in upcoming years. ★

Rocket manufacturers continue to bet big on reusability

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.

BY ZACHARY FRIEDMAN AND AMRUTUR ANILKUMAR

This was perhaps the most significant year for reusable rocket development, with reusability records, all-time highs in investment and novel technology development. It was also a challenging year for launch providers, including the shutdown of small-satellite launcher **Virgin Orbit** in May and August layoffs at California-based launch firm **Astra**.

With the commercial launch market becoming consolidated, U.S. national security space is providing a lifeline for companies. In February, the **U.S. Space Force** released a solicitation for **Phase 3 of the National Security Space Launch program** for approximately 70 launches between 2027 and 2032. Plans call for contracts to be organized into multiple procurement "lanes," including one lane allowing for an unlimited number of firms to compete for up to 30 launches of up to 6,800 kilograms to low-Earth orbit. In addition to selecting multiple heavy-lift providers, the Space Force plans to award contracts to a variety of medium-lift providers, which opened the competition to a greater variety of companies than in the past.

SpaceX continued to lead the charge on reusability, including in November when the company set a new record with the 18th launch and recovery of a **Falcon 9** booster. SpaceX has also been heavily focused on the development of its **Starship rockets**. NASA has contracted SpaceX to build a Starship to ferry astronauts to the lunar surface under the **Artemis** program. In November, SpaceX conducted the second development flight with a fully stacked Starship-Super Heavy. As planned, the stages separated over the Gulf of Mexico. Shortly after, Super Heavy exploded at an altitude of 90 kilometers, while Starship proceeded on for some minutes, reaching an altitude of 148 kilometers before it was lost. The flight built on the April attempt, in which the rocket reached an altitude of 39 kilometers.

Rocket Lab, a leading provider of small-lift rockets, continued to make reusability progress for both of its launch vehicles. In August, the California-based company flew the first reused engine on an **Electron** rocket. Rocket Lab also tapped into the defense hypersonic market with the first launch of its Hypersonic Accelerator Suborbital Test Electronic, or **HASTE**, vehicle in June, a hypersonic testbed comprised of a modified Electron booster. Like competitors, Rocket Lab's priority investment is toward developing a larger, fully reusable vehicle. This medium-lift design, named **Neutron**, is to debut in 2024. To date, Rocket Lab has received $24 million in contracts from Space Force's Space Systems Command for Neutron and must now fly one by October 2026 to be eligible to compete for the first year of Phase 3 contracts.

In March, **Relativity Space**, a rocket manufacturer based in California and known for its heavy reliance on metal 3D printing, launched its inaugural **Terran 1**. The small-lift vehicle failed to reach orbit when the engine on its second stage "did not reach full thrust," the company said in a series of posts. In April, Relatively announced plans to abandon Terran 1 development to focus on its larger **Terran R** design, which is to be fully reusable. In posts on X (formerly Twitter), Relativity said the biggest opportunity is in the medium-to-heavy lift market. As of October, Relativity has pre-sold $1.2 billion worth of commercial launch agreements for Terran R and aims for a first launch in 2026.

In September, **Stoke Space** flew a prototype of its second stage rocket for the first time. The **Hopper2** test vehicle from the company's facility in Moses Lake, Washington, rose to an altitude of 9 meters then landed vertically "at its planned landing zone," Stoke said in a press release. The test demonstrated Stoke's unique design, which consists of a ring of small engines wrapped around a heat shield. That second stage design is to be one part of a fully reusable **Nova** rocket that Stoke plans to fly in 2025. ★

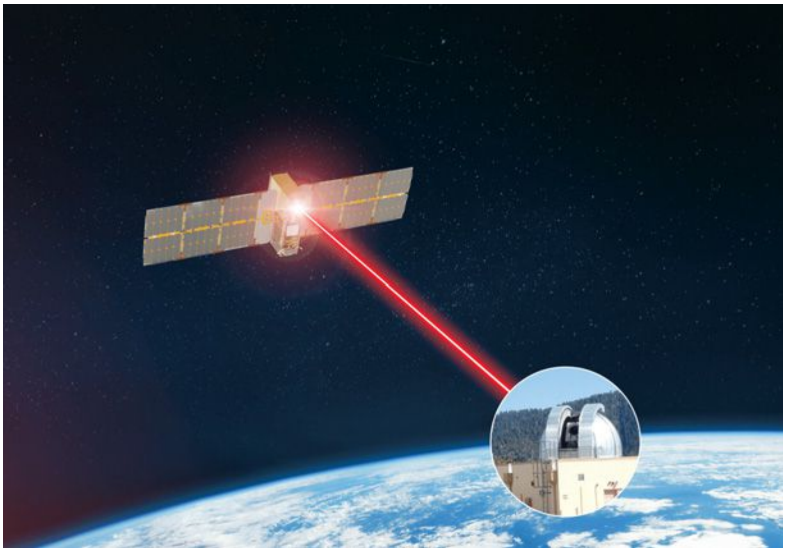
▼ Stoke Space in September conducted a hover test of its Hopper2 prototype. This design is to be the second stage of Stoke's planned Nova rocket, scheduled for an inaugural flight in 2025.

Stoke Space

A year of firsts: optical communications, autonomy and hacking

BY MICHAEL SWARTWOUT, GIOVANNI MINELLI 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.



▲ NASA and MIT in April demonstrated a downlink rate of 200 gigabits per second via optical links with the TeraByte InfraRed Delivery payload. This tissue-box-sized terminal is installed in the Payfinder Technology Demonstrator 3 cubesat, built by Terran Orbital of California.
NASA

From technology demonstrations to high-data-rate communications and Earth observations, small satellites are important platforms for a diverse set of national, commercial and educational missions. In April, the NASA/MIT Lincoln Laboratory **TeraByte InfraRed Delivery** payload, aboard the **Pathfinder Technology Demonstrator 3** cubesat, sustained a 200 gigabit-per-second data downlink rate to transfer more than 1.4 terabytes of data in a single five-minute ground pass. This is the highest-recorded rate for a **space-to-ground optical link**, and the technology proved effective in both nighttime and daylight operations. The ground and space segments aligned with one another via guided laser beams, which accomplished pointing errors below 40 microradians; this error was well within the payload's 380-microradian beamwidth. Optical communications are desirable because of this order-of-magnitude increase in bandwidth, but also because of the increased security from a narrow beam and the lack of licensing required to operate these links.

In May, MIT's **Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats, or TROPICS**, were launched weeks apart into two 32.75-degree, 550-kilometer orbits. Each of the four cubesats carries a **microwave radiometer** capable of nearly all-weather observations of 3D temperature and humidity, cloud ice and precipitation horizontal structure. The purpose of these NASA-sponsored spacecraft, built by Colorado-based **Blue Canyon**, is to conduct scientific investigations of tropical cyclones. By placing two pairs of cubesats into two orbital planes, meteorologists can gain a more complete picture of rapidly developing activity. The initial results show a promising future for high-performance meteorological cubesats.

In July, California-based **Rocket Lab** launched four cubesats for **NASA's Starling** mission. Plans call for demonstrating autonomous command and control capabilities for swarm missions, including swarm control, adaptive communications and autonomous event response.

The **Hack-A-Sat 4** cyber competition in August invited teams to hack the first orbital hacking sandbox, **Moonlighter**, a three-unit cubesat developed by **Aerospace Corp.** and the **U.S. Air Force Research Laboratory** and was built specifically for this activity. The competition winners, the Italian mHACKeroni team, commanded the spacecraft to capture and downlink an image to their ground terminal. The **U.S. Space Force** uses this competition to learn about and improve potential security weaknesses.

Among these demonstrations, however, were signs of a slowdown in the small satellite industry. From 2021 to 2022, an average of 10 new and 43 existing commercial constellations added an average of 296 spacecraft per year. In 2023, those numbers were down to six, 37 and 212, respectively. The most significant entrant was the **Space Development Agency** of Virginia, whose first spacecraft in the **Tranche 0 Tracking and Transport** layers of its **Proliferated Warfighter Space Architecture** were launched in April and September. The Tranche 0 layers will demonstrate advanced missile warning and low-latency communications links between air and ground systems.

The path to orbit for small satellites became more constrained this year. In 2021, there were dozens of flights on 11 launch systems available to customers around the world. Due to the delays in the development of new launchers, cancellations of other programs and the ongoing sanctions against the use of Russian-made rockets, commercial satellite programs in the West had 18 flights across four launch options in 2023: four flights on **SpaceX Transporter rideshare** launches, eight on **Rocket Lab's Electron rockets,** one on a Vegas rocket and five cargo flights to the **International Space Station**.

Small satellites continue to be an effective means for organizations and nations to access space: Sixty universities and private companies orbited their first spacecraft this year. In January, **Kuwait** became the 78th nation to fly its own spacecraft with the launch of **KuwaitSat-1** on **SpaceX Transporter-6**.★

Contributors: *Kerri Cahoy and Paula do Vale Pereira*

Expanding the boundaries of space habitat design

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.

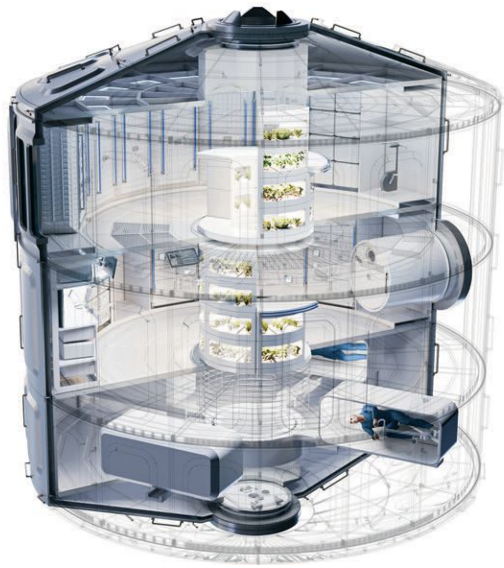
The past year saw progress on several frontiers, including **artificial gravity** and **larger monolithic modules** designed in anticipation of a new generation of **super-heavy launchers,** as well as rapidly developing **inflatable structure technology**.

In April, Germany-based **Airbus Defence and Space** and Austria-based **LIQUIFER Systems Group** unveiled concepts for the **Airbus LOOP** multipurpose orbital module. Plans call for a single cylindrical module 8 meters in diameter and length, divided lengthwise into three sections for a habitation deck, a science deck and a centrifuge for periodic crew sessions in artificial gravity.

In May, **Vast** of California announced a contract with **SpaceX** to launch the **Haven-1** space station as early as August 2025, and later the first four-person crew that will spend up to 30 days aboard the station. Vast plans for Haven-1 to operate initially as an independent station providing microgravity and lunar-strength artificial gravity environments, with the long-term goal to develop 100-meter-long multimodule artificial gravity stations. In June, **NASA** announced that it selected Vast as one of seven U.S. companies in its second iteration of the **Collaborations for Commercial Space Capabilities initiative**, in which the agency will provide "technical expertise, assessments, lessons learned, technologies, and data."

In June, Alabama-based **Above Space Development Corp.**, formerly known as **Orbital Assembly**, tested a 1:2-scaled model of its **Iota** artificial-gravity platform at the air-bearing "flat floor" facility at **NASA's Marshall Space Flight Center** in Alabama. The test spun up the model and validated its control systems, software and propulsion system. The full-scale Iota is to be an automated, uncrewed artificial gravity platform for commercial customers in low-Earth orbit as a precursor to larger crewed platforms, such as the company's planned **Pioneer-class station**.

Also in June, a consortium of companies led by **Voyager Space** of Colorado completed the system requirements review for the planned **Starlab** space station under a **Space Act Agreement** with NASA. In August, **Voyager** and **Airbus Defence and Space** announced they would jointly develop, build and operate Starlab. Virginia-based Hilton Hotels and Resorts is supporting the design and development of crew suites. Plans call for Starlab to achieve initial operational capability in 2028, prior to the decommissioning of the **International Space Station**.



◀ LIQUIFER Systems and Airbus Defence and Space in April unveiled this concept for a multistory orbital module for crews of four to conduct experiments in low-Earth orbit. Airbus is jointly developing a free-flying space station called Starlab with Voyager Space, but the companies have not said whether the modules would be used.

LIQUIFER Systems Group

Lockheed Martin in June conducted a second successful burst test of a subscale model of an **inflatable module**, reaching a contained pressure of 1,744 kilopascals (253 pounds per square inch or 17.2 atmospheres), nearly six times the maximum operating pressure before its explosive rupture. This followed an earlier test in December 2022. Future test plans include subscale creep and life-span deformation, as well as full-scale burst.

The pool of potential astronauts also widened. In April, **John McFall**, the world's first "parastronaut" candidate, participated in a weightless parabolic flight sponsored by the **European Space Agency** and **Novespace** in Bordeaux, France. McFall, a world-class paralympic athlete who lost his right leg in a motorcycle accident years ago, was one of 17 astronaut candidates selected by ESA in 2022.

In the **suborbital** realm, two companies advanced plans to loft tourists to the edge of space with **stratospheric balloons** and luxurious **pressurized capsules**. In April, **Zephalto** of France announced a partnership with the **French National Center for Space Studies** to develop its balloon and **Céleste** capsule to carry six passengers and two pilots to an altitude of 25 kilometers (82,000 feet), "above 98% of the atmosphere." In August, **Space Perspective** of Florida opened its **Seely SpaceBalloon Factory**. Its **Spaceship Neptune** capsule will seat eight passengers and one pilot ascending to 30 km (100,000 feet), "above 99% of the Earth's atmosphere." ★

Contributor: *Barbara Imhof*

Space robotic arms and rovers push the limits of lunar exploration

BY SAMANTHA CHAPIN, ERIK KOMENDERA AND JIAN-FENG SHI

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

In January, **NASA** and **industry collaborators** published a paper on the **Space Robotics Operating System**. This open-source framework for writing space robotic flight software aims to create a quicker path to flight and lower the cost of new missions.

In February, NASA selected the **Aerospace Corp.** to operate the **Consortium for Space Mobility and ISAM Capabilities** to bring together industry, academia and government to collaborate on in-space servicing, assembly and manufacturing development.

In March, progress was made on multiple lunar rovers. NASA began assembly of its **Volatiles Investigating Polar Exploration Rover, or VIPER**, at **Johnson Space Center** in Texas, integrating instruments delivered from **NASA's Kennedy Space Center** in Florida and **NASA's Ames Research Center** in California. NASA also released a draft strategy for continued exploration of Mars, outlining plans for robotic missions following the **Mars Sample Return** mission. **Canada** announced that its federal budget included $1.2 billion to create a **lunar utility vehicle**. The **Australian Space Agency** awarded grants for **Trailblazer Stage 1**, a program to design a lunar rover that can collect regolith and deliver it to a NASA in situ resource utilization facility. Japanese company **GITAI** used two rovers each equipped with dual robotic arms to demonstrate lunar base construction in a Californian desert environment that simulated the lunar surface.

Also in March, **NASA's Jet Propulsion Laboratory** and **Motiv Space Systems** of California published a journal article about their **Cold Operable Lunar Deployable Arm**, describing the development and testing for component and system technologies that would allow this robotic arm to operate in extremely cold environments, such as lunar nights. In April, Motiv announced its partnership with **PickNik Robotics** of Colorado to upgrade the **xLink** robotic arm to use **MoveIt Studio** software, aiming to create a more capable robotic manipulator for ISAM.

In June, **NASA's Cooperative Autonomous Distributed Robotic Explorers project** completed its first autonomous driving test with a model rover in **JPL's Mars Yard** in California. A trio of rovers are being built for a **Commercial Lunar Payload Services** lunar mission that aims to show how multiple autonomous robots can simultaneously take measurements across different locations. Additionally, the JPL-funded **Multi-Modal Mobility Morphobot project** published testing results. The M4 rover, led by professors at **Caltech** and **Northeastern University**, was designed with four articulatable wheels with embedded propellers, prototyping the next generation of rovers that could autonomously adapt to their terrain and circumvent obstacles by morphing modes of traversing, including driving, walking and flying.

In June, **Northrop Grumman's SpaceLogistics** sold its third **Mission Extension Pod** to **Intelsat**. This "jet pack" is attached to legacy satellites to provide propulsion. The pods will be installed by SpaceLogistics' **Mission Robotic Vehicle**, which is equipped with a pair of **DARPA's Robotic Servicing of Geosynchronous Satellites robotic arms** built by the **U.S. Naval Research Laboratory** in Washington. Researchers completed all component-level testing in November 2022.

In July, NASA announced a Tipping Point award to **Astrobotic Technology**. The Pennsylvania company is to land its Griffin lander to the moon to demonstrate robotic deployment of a power cable across the lunar surface with its CubeRover. NASA selected **Protoinnovations** of Pennsylvania to mature mobility control software for lunar robots and rovers. **Redwire** of Florida was selected to build lunar infrastructure, such as landing pads, using microwave emitters to heat and solidify regolith.

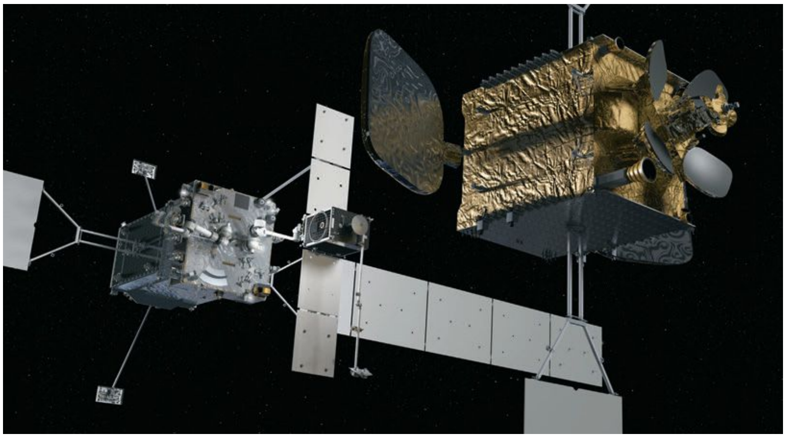
In August, the **Indian Space Research Organization's Vikram lander** touched down near the lunar south pole. The lander deployed the **Pragyan rover**, which in September completed its first motion and data collection tasks. ★

▼ NASA engineers this year conducted an egress test with the model of the agency's VIPER, short for Volatiles Investigating Polar Exploration Rover. The rover is scheduled for launch late next year aboard an Astrobotic Griffin lander. After the lander touches down at the lunar south pole, VIPER will have to descend at a height and angle similar to the setup in this picture.
NASA/Dominic Hart

Space logistics: A burgeoning commercial market

BY HAO CHEN AND KOKI HO

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



▲ Intelsat this year purchased two SpaceLogistics Mission Extension Pods, an example of which is shown at the center of this illustration. The Mission Robotic Vehicle (at left) would attach this pod to a client satellite. The pod would remain docked for a number of years, providing propulsion and pointing control.

Northrop Grumman

Technology development of **in-space servicing, assembly and manufacturing, or ISAM**, increasing concern about space debris and the global enthusiasm for space exploration are fostering a new commercial market for space logistics. This year, multiple market research companies, such as **Brainy Insights** in India, **Allied Market Research** of Delaware and **Report Ocean** in India, estimated the space logistics market size will reach $20 billion in the 2030s.

Government investment in space technology development propelled the growth. In April, **NASA** formulated and funded the **Consortium for Space Mobility and ISAM Capabilities, COSMIC**, to foster nationwide collaboration across government, industry, nonprofits and academia. The **Aerospace Corp.** was selected to operate the group. In March, NASA awarded **Redwire** of Florida a $5.9 million contract to complete the design of **FabLab**, a new in-space manufacturing system. In June, NASA entered into a Space Act Agreement with **Sierra Space** of Colorado for the development of the company's commercial low-Earth orbit ecosystem, including new space station architectures and in-space logistics and servicing. NASA will provide access to facilities and support for environmental and crew systems testing, tools and software.

In the commercial market, **Intelsat** purchased two **Mission Extension Pods** from **SpaceLogistics**, a satellite-servicing company owned by **Northrop Grumman**, in April and in June. These propulsion pods are scheduled to be attached to Intelsat communication satellites in geosynchronous orbit in early 2025.

The same market growth trend appeared in Europe. In February, French space services company **Exotrail** announced that it raised $58 million in a Series B funding round to expand its in-space transportation services. In April, the **Italian Space Agency** awarded a 235-million-euro contract to a **Thales Alenia Space-led consortium** to design, develop and build an in-orbit servicing demonstration mission. The contract was funded through the in-orbit economy component of the Italian national covid-19 recovery scheme, which is part of the European Union's Next Generation EU economic package.

In February, the **U.S. Space Force** awarded Colorado-based **CisLunar Industries, Astroscale U.S.** and **Colorado State University** a $1.7 million **Direct-to-Phase II Small Business Innovation Research** contract to recycle space debris into metal propulsion. In March, the Space Force awarded a $1.6 million SBIR contract to a team led by Southern California startup **Arkisys** to demonstrate satellite assembly capability in orbit. In July, the Space Force awarded a $1.7 million Direct-to-Phase-II contract to California-based **Orbital Composites**, partnering with **Axiom Space, Northrop Grumman and Southwest Research Institute**, to build and launch the first space factory for kilometer-scale antennas within the next three to five years.

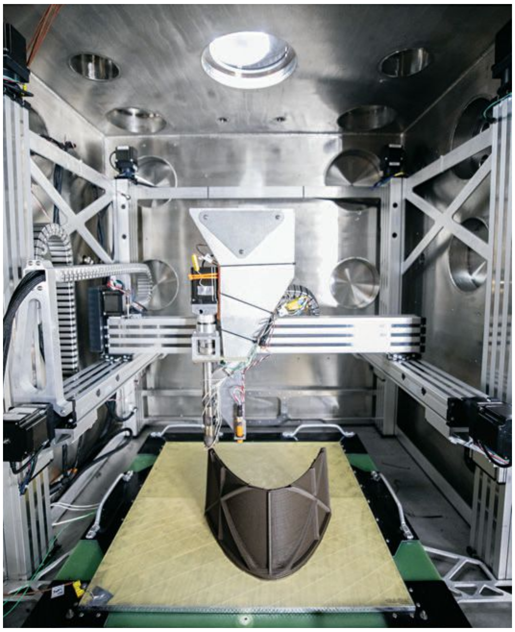
In the realm of moon and Mars transportation, **NASA** in May selected **Blue Origin** of Washington as the second lunar lander provider for the **Artemis** program, awarding a $3.4 billion firm-fixed price contract. In July, **DARPA** contracted Lockheed Martin to design and build a nuclear-powered rocket, with an in-space flight demonstration scheduled for 2027. The Space Force will provide launch and launch site support for the test.

In academia, **NASA's Office of Technology, Policy and Strategy** awarded two teams funds to examine policy opportunities and perform space logistics analysis for commercialization of debris remediation. The lead institutions are **Princeton University** and the **Stevens Institute of Technology**, both in New Jersey. Also, as part of the **Space University Research Initiative** program, the **Air Force Office of Scientific Research** awarded three new teams contracts for space logistics research and development. Each will receive up to $5 million ($3 million base plus a $2 million option).The lead institutes are **Georgia Tech**, the **University of California, Santa Cruz** and **Cornell University** in New York. ★

Space resource exploration and demonstration missions advance

BY CHRISTOPHER B. DREYER

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.



◀ Engineers this year demonstrated 3D printing of a subscale version of the structure of LINA, a proposed lunar outpost. Designed by AI Space Factory of Alabama in collaboration with NASA Kennedy's Swamp Works division, LINA is comprised of a polymer-regolith composite.
NASA Kennedy Space Center/Swamp Works

Lunar resource exploration missions made several advances in 2023. In June, a prototype of NASA's **Volatiles Investigating Polar Exploration Rover, or VIPER**, completed egress tests from a model of a **Griffin** lander built by **Astrobotic Technology** of Pennsylvania. **Griffin** is scheduled to land VIPER on the lunar south pole in late 2024, where the rover will search for ice and other potential resources. The tests, conducted with the VIPER prototype **Moon Gravitation Representative Unit 3** at **NASA's Ames Research Center** in California, demonstrated the rover's ability to traverse the lander ramp over a range of conditions. In August, after two decades of effort, **Honeybee Robotics** in California delivered avionics packages and two 1-meter-class **TRIDENTs, The Regolith and Ice Drill for Exploring New Terrain**, to **Intuitive Machines** of Texas and **NASA's Johnson Space Center** in Texas. One TRIDENT will be ferried to the lunar surface aboard an Intuitive Machines **Nova-C** lander for the **Polar Resources Ice Mining Experiment-1 mission;** the other will be installed on VIPER. Onboard PRIME-1, TRIDENT will collect **subsurface regolith** for analysis by a mass spectrometer.

In September, NASA announced that the **Mars Oxygen In-Situ Resource Utilization Experiment** completed its mission on Mars. **MOXIE**, aboard the **Perseverance** rover, produced **molecular oxygen** 16 times over one Martian year of operations under a variety of conditions. Production was consistently 12 grams per hour, double the mission goal. MOXIE demonstrated valuable lessons on how to operate the system on Mars, according to Michael Hecht, the project's principal investigator. Future scaled-up MOXIE systems could produce **oxygen for rocket propellant and astronaut consumption**, reducing the need to bring theses consumables from Earth.

In March, **NASA** announced the winners of the **Lunar Forge Challenge**. Seven university teams won a combined $1.1 million in awards as part of the **NASA Breakthrough, Innovative and Game-Changing Idea Challenge**. Teams will compete to develop a variety of concepts for technologies needed in the lunar metal production pipeline.

This year, teams completed **Phase 2** of the **NASA Break the Ice Lunar Challenge**, in which they developed their systems and demonstrated their operation in a 15-day endurance test. NASA plans to announce the winners by the end of the year. The top teams for Phase 2a were announced in December 2022. Fifteen teams were selected to compete for a chance to win prizes totaling $3.5 million.

In February, **Blue Origin** of Washington announced the results of its **Blue Alchemist** project, a technology demonstration to produce solar cells from lunar regolith simulants. Via **molten regolith electrolysis**, a reactor produced iron, silicon and aluminum. The silicon- and regolith-derived glass are then used to make solar cells. Regolith-derived aluminum is used for transmission wire. Blue Origin believes this technology will make a long-term human lunar presence viable by producing abundant electrical power.

In March, **AI Space Factory** of New Jersey, in collaboration with **Swamp Works** at **NASA's Kennedy Space Center** in Florida, completed the **Regolith Additive Construction Technology** demonstration. They 3D printed a scaled lunar outpost **LINA** in a vacuum from a mixture of regolith and polymer. The printed structure was engineered to withstand lunar conditions and support a regolith radiation shield.

In March, the **EPE and Lunar Outpost Oceania Consortium** and the **Australian Remote Operations for Space and Earth** received grants of 4 million Australian dollars ($2.6 million) under the **Australian Space Agency's Moon to Mars: Trailblazer** program, which with NASA is working toward the first end-to-end space resources demonstration on the moon. The organizations are to create a rover to autonomously collect and transfer lunar regolith to a NASA processing facility that would extract oxygen from the regolith. ★

Contributors: *Michael Hecht, Kevin Hubbard, Joseph Kendrick, Julie Kleinhenz, Jared Long-Fox, Laurent Sibille and Kris Zacny*

Advancements made toward long-term thriving human communities in space

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.

Overall, it has been an exciting year for space settlement, including multiple launches and advancements in making life off Earth more habitable. Although not all objectives were completed, SpaceX's April and November launches of **Starship-Super Heavy rockets** hinted at the possibility of sending large masses to orbit and beyond — key components for enabling thriving communities. As the price for mass to orbit drops, more options for space development become available.

India's autonomous lander and rover landed on the moon in August, and results from those spacecraft — as well as the the samples retreived by China's **Chang'e-5** lander in 2020 — confirm the availability of critical resources, including **oxygen and metals**, and hint at the ability to grow plants in enclosed volumes on the moon. To enable larger-scale lunar settlements, resources including **carbon, nitrogen and water** must be found in large quantities on the moon or brought from Earth.

On Mars in September, NASA's **Mars Oxygen In-Situ Resource Utilization Experiment, MOXIE**, completed its mission aboard the **Perseverance** rover. MOXIE demonstrated a way to collect carbon dioxide from the Martian atmosphere and convert it to oxygen, which will be required for astronaut consumption during long-term Mars missions, as well as for generating rocket fuel.

In low-Earth orbit, **plant growth experiments** continued on the **International Space Station** and on the **Chinese Shenzhou station**. Plant growth recycles air and water in space and adds fresh food to stored rations and food shipped from Earth. In February, the **Human Research Facility Veggie, HRF Veg**, project surveyed the psychological benefits of eating the fresh salad crops grown on ISS. Plants on ISS essentially grow in pillowlike fiber bags, which contain added nutrients like nitrates, into which astronauts inject water. Astronauts' mood improved after eating the crops. Larger-scale growing technology could be adapted from hydroponic technologies from Earth.

Since space settlement is a long-term endevor, several contests and projects this year engaged middle school to high school students from dozens of countries around the world, who created impressive and imaginative space settlement designs. One example was the **National Space Society Gerard K. O'Neill Space Settlement Contest** completed in February. It featured 26,725 students, who submitted 4,567 entries from 19 countries. The grand prize was awarded in May to a team of seventh graders from **St. Cecilia School** and **San Francisco Japanese School**, both in San Francisco. Their design featured both physical models and computer-assisted designs for a free-space rotating settlement called Space. NoA+. The fourth edition of the **Martian Greenhouse Project** began in October with a request for proposals from middle school and high school students around the world, who are challenged to design future **self-sustaining space settlements on Mars** using project management and engineering principles. Each team is partnered with mentor engineers. The project culminates with presentations, including models, cost projections and other metrics.

The capstone contest for high school students is the **International Space Settlement Design Competition**, which began in February with several global regional competitions. The competition required detailed budgeting, project planning, detailed designs and project dynamics similar to actual aerospace projects, including similar deadlines. Finalists go to a NASA field center for an intensive 48-hour engineering final contest, which took place in July at **NASA's Kennedy Space Center** in Florida. Winning teams are not typically published to encourage future collaboration, but in the past, participants included teams from the U.S. and U.K. ★

▲ United Arab Emirates astronaut Sultan Al Neyadi harvests tomatoes grown on the International Space Station under the Human Resource Facility Veggie project. In HRF Veg, researchers survey the psychological and health benefits astronauts gain from growing and eating fresh produce on-orbit. The technology used to grow these tomatoes would need to be scaled up for future human space settlements in orbit, or on the moon or Mars.

Mohammed Bin Rashid Space Centre

A year of growth for large constellations and commercial spaceflight

BY ANDREW WOODCOCK

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

▲ SpaceX in February launched the first batch of V2 Mini satellites for its Starlink internet constellation. The company shared this photo of the 21 satellites in a post on X, formerly Twitter, before they were enclosed in the Falcon 9 payload fairing.

SpaceX

In **low-Earth orbit**, the development and deployment of internet constellations continued apace. In February, **SpaceX** launched the first batch of second-generation **Starlink** satellites. These **V2 Minis** are larger than the V1 and V1.5 satellites, which SpaceX says translates to "more bandwidth and increased reliability" for customers. SpaceX is designing a larger V2 variant that would be launched aboard the company's planned **Starship-Super Heavy** launch vehicles. As of October, 508 V2 Minis were launched, and 428 were in orbit as part of the over 5,000-satellite constellation.

In October, the inaugural satellites for another constellation builder, **Amazon's Project Kuiper**, were launched aboard a **United Launch Alliance Atlas V**. ULA is one of three launch providers that Project Kuiper has signed contracts with for a combined 80 launches of 3,236 broadband satellites. On its website, Amazon says Project Kuiper will "increase global broadband access" by bringing "fast, affordable broadband to unserved and underserved communities around the world."

In January, the **U.S. Department of Commerce's Office of Space Commerce** published a request for information regarding its efforts to begin providing **space situational awareness** services for civilian satellites. The RFI solicited comments from "spacecraft operators, SSA data providers (current and prospective, ground and space-based), SSA analytic and value-added service providers, academia, nonprofit entities, space insurance providers, and the legal community" on its proposed **Traffic Coordination System for Space, or TraCSS**. The Office of Space Commerce was charged in 2018 with taking over tracking of debris and civilian spacecraft from **U.S. Space Command** and is targeting 2024 to begin offering these services via TraCSS.

In July, **NOAA** eliminated a series of conditions on Tier 3 on **commercial remote sensing** satellite licenses that had previously restricted these operators from collecting imagery under certain conditions.

In April and September, a combined 20 satellites were launched for the U.S. Space Development Agency's planned **Proliferated Warfighter Space Architecture**, a seven-layer network of satellites and ground stations. These initial satellites, called **Tranche 0**, are designed to demonstrate low-latency tactical datalinks for future services, including missile tracking.

In the realm of human spaceflight, **SpaceX** in May launched a second crew of tourists to the International Space Station for **Axiom Space** of Texas. In September, Axiom announced the crew for the third spaceflight, scheduled to be launched in January 2024 at the earliest: Axiom Chief Astronaut Michael López-Alegría, who will command the mission; Alper Gezeravci of Turkey; Italian Air Force Col. Walter Villadei; and Marcus Wandt of Sweden, who is sponsored by the European Space Agency and Swedish National Space Agency. They are to spend up to 14 days on ISS conducting research, among other activities.

Beyond low-Earth orbit, **NASA** continued preparations for future lunar missions under its **Artemis** program. In April, the agency announced the crew for the **Artemis II** lunar flyby: NASA astronauts Reid Wiseman, Victor Glover and Christina Hammock Koch, and Canadian Space Agency astronaut Jeremy Hansen. In May, **Blue Origin** was awarded a $3.4 billion fixed-price contract to provide the lander for the **Artemis V** lunar landing, scheduled for 2029. As part of the contract, Blue Origin must demonstrate it can land an uncrewed lander on the lunar surface before NASA will permit it to carry astronauts. In August, **SpaceX** test fired the engines for its lunar lander variant of its **Starship** design, which will ferry NASA astronauts from lunar orbit to the surface and back in the **Artemis III** and **Artemis IV** landings. Plans call for Artemis III to occur in 2025, though NASA has said that could slip to 2026, and for Artemis IV to take place in 2028. ★

Contributors: *John Carsten and Bill Tomek*

New mission concepts emerge

BY SVEN G. BILÉN

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

After a flurry of missions the past several years, the community this year focused on developing new concepts for **tether transport systems,** as well as the subsystems required to realize space tether missions and prepare for future flight opportunities.

Through two projects funded by the **National Science Foundation**, researchers at the **University at Buffalo** in New York carried out research on tethers for the capture and removal of **uncooperative space objects**. In January, they described relative distance controllers for a **chaser-tether-target system** and analyzed the controllers' performance, focusing on safety. In July, the researchers demonstrated a **decentralized actuation system** combined with reinforcement learning for increasing the robustness of target capture via a net. In September, they proposed an estimation algorithm to determine the inertia parameters of tethered uncooperative space debris using landmark tracking and a tension sensor.

In January, researchers at **Nanjing University of Aeronautics and Astronautics**, with funding from the **National Natural Science Foundation** of China and the **Qing Lan Project of Jiangsu Province** universities and colleges, proposed a deep learning scheme of **nonlinear predictive control** for deorbiting an electrodynamic tether. In their scheme, a large dataset is generated first via a conventional control law to train a **deep neural network**. Then, the trained deep neural network realizes the real-time mapping from the system state to the system control, thereby providing feedback control of the system deorbit with low computational cost.

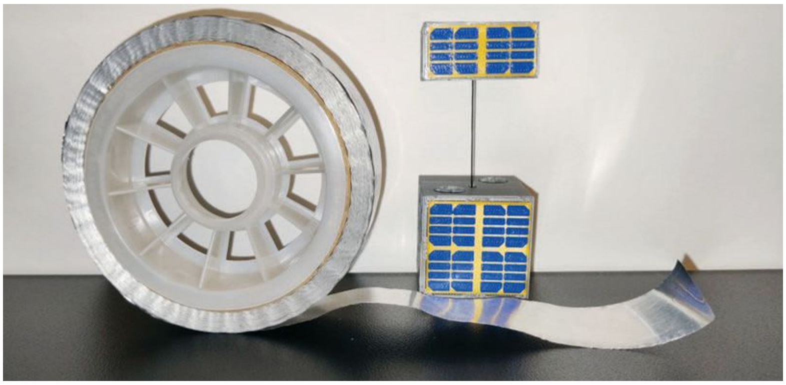
Through funding from the **Russian Science Foundation**, researchers at **Samara University** in August delivered their study on using a tethered system to explore the surface of **Phobos**, a Martian moon. They analyzed the dynamics of a tether in the framework of the circular restricted three-body problem. They presented two cases: one of tether attachment to a spacecraft located at the libration point of the Mars-Phobos system, and another moving in a quasi-satellite orbit around Phobos. The researchers proposed control laws for tether tension and end-body thrusters, and their results were validated via numerical simulations.

Researchers at the **University of Strathclyde** in Scotland investigated the potential for two-way Earth-Mars exchanges of freight payloads using **motorized momentum exchange tethers**. They presented their methodology, which identified possible orbits for symmetrical double-payloaded motorized tethers and for their payloads around both Earth and Mars, by applying reusable dummy payloads for symmetrical load balancing. In all cases, the orbits of the tethers were highly elliptical with apoapsis radii greater than 50,000 kilometers, which allows the tethers to have velocities close to, but below, the escape velocity at the periapsis of their corresponding orbits. They also began research on the use of a **spaceplane** for payload delivery and reconnaissance and the recapture of missed payloads.

In April, manufacturing of a 12-unit, 24-kilogram deorbit device was begun under the **Electrodynamic Tether Technology for Passive Consumable-less Deorbit Kit-Fly, or E.T.PACK-F**, project funded by the European Innovation Council. In October, they began integrating their model with a 1-kilogram, 500-meter **aluminum tape tether** for electrodynamic drag. Plans call for the qualification, production and testing of a flight model in 2024 in preparation for a mid-2025 in-orbit demonstration funded by the **European Commission**. 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, the Spanish company **SENER Aeroespacial** and the German startup **Rocket Factory Augsburg**. ★

▼ A sample of the aluminum tape that a consortium of researchers plans to install on a satellite to test whether a spacecraft can be deorbited via electrodynamic-tether technology. Plans call for an in-flight demonstration in mid-2025.

Electrodynamic Tether Technology for Passive Consumable-less Deorbit Kit-Fly



From SpaceX to Chandrayaan-3, operators achieve new heights

BY DALE ARNEY

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

Space transportation this year is set to surpass the record 186 orbital launches conducted in 2022, which broke the previous record of 146 in 2021. Driving the industry was **SpaceX's Falcon 9** fleet, which surpassed 2022's record-breaking launch total with its 62nd launch in September. SpaceX averaged a Falcon launch every four days through that month.

In July, **NASA** completed a hot fire test of a modified **Aerojet Rocketdyne RS-25** engine at **NASA's Stennis Space Center** in Mississippi in preparation for future **Artemis** missions. The Artemis moon program kicked off in November 2022 when a **Space Launch System** rocket lofted an unoccupied **Orion** spacecraft to orbit for a loop around the moon.

The **Falcon 9** continued to be SpaceX's workhorse launcher. The 200th launch was conducted in February, and a booster was reflown a record 18th time in November. In July, a **Falcon Heavy** launched **Jupiter-3** from **NASA's Kennedy Space Center** in Florida, the heaviest commercial geostationary satellite ever built. In November, **SpaceX** performed the second flight test of a **Starship spacecraft and Super Heavy booster** from its Texas facility. As planned, Super Heavy and Starship separated via an updated **hot-staging technique**. Shortly after separation, Super Heavy exploded while Starship proceeded on for some seconds but was lost. FAA announced that SpaceX would conduct a "mishap" investigation. During the truncated April attempt, control was lost shortly after liftoff and the vehicle was destroyed.

In June, **United Launch Alliance** of Colorado launched the penultimate flight of the **Delta IV Heavy**. The final flight is planned for 2024. As of November, ULA planned to conduct the inaugural launch of its **Vulcan-Centaur** rocket on Christmas Eve, after a structural failure in the second stage during a March pressure test prompted additional testing.

Crew and cargo delivery to the **International Space Station** continued with the final launch of **Northrop Grumman's Antares 230+** rocket in August, two crew rotations aboard SpaceX Falcon 9 rockets and **Crew Dragon** spacecraft in March and August, and the private **Axiom-2** mission in May that sent private citizens to the station.

In January, California-based **Rocket Lab** conducted the first launch of an **Electron** from Virginia. In August, the company reused a previously flown **Rutherford** engine on its 40th mission.

In March, **Relativity Space** of California launched its first 3D-printed, methane-fueled **Terran 1** rocket from Cape Canaveral, Florida. After an issue with the second stage, the launcher failed to reach orbit, and the company announced it was canceling future Terran 1 launches to develop the larger **Terran R** rocket.

▲ In April, a SpaceX Starship-Super Heavy became the most powerful rocket to be launched. The test flight from Boca Chica, Texas, ended approximately four minutes after liftoff when thrust vector control of the vehicle was lost, among other problems.
SpaceX

The **RS1** launcher from **ABL Space Systems** of California failed to reach orbit in its first launch attempt from Alaska in January.

California-based **Virgin Galactic** returned to crewed suborbital flights in May after a nearly two-year absence, and the company began commercial operations in June. As of November, Virgin had conducted five commercial flights in its **VSS Unity** spaceplane with government astronauts and private tourists.

The global space industry also saw several achievements. India became the fourth nation to land a spacecraft on the moon with its **Chandrayaan-3** mission. In July, a **Launch Vehicle Mark-3** launched a lander with its rover, which touched down near the **moon's south pole** in August. In China, **Space Pioneer** for the first time launched its **Tianlong-2** in March, and **LandSpace's Zhuque-2** methane-fueled rocket reached orbit in July. China averaged one launch per week during the first half of the year. In July, **Arianespace** launched the last **Ariane 5** from French Guiana in July, making way for the **Ariane 6**, which is scheduled to debut in 2024. ★

Drones, hypersonics and missile defense

BY NICHOLAS J. MUESCHKE AND 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.

The **Russia-Ukraine war** displayed various aspects and new developments in defense and weapons system use. In April, two U.S.-made **Patriot missiles** and air defense batteries arrived in Ukraine. The Ukrainian air force later claimed that with the missiles, they downed Russian drones, subsonic cruise missiles and aircraft, and even intercepted seven **Russian Kh-47 Kinzhal** air-launched hypersonic missiles over the course of a few weeks. In August, Germany agreed to supply additional **Patriots** to Ukraine.

In the United States, the **Missile Defense Agency** reported that the **Flight Test Aegis Weapon System 31 Event 1a** was conducted in March. Two **SM-6** missiles, launched by the **U.S. Navy** from the guided-missile destroyer **USS Daniel Inouye** in the Pacific Ocean, intercepted a medium-range ballistic missile target launched from the nearby **Pacific Missile Range Facility** in Hawaii. The test evaluated the Aegis Weapon System's ability to detect, tract and intercept an incoming ballistic missile in the terminal phase of its attack and furthered sea-based ballistic missile defense capabilities to protect ship and shore assets.

In the area of offensive hypersonic weapons, **Lockheed Martin** in February received a $1.2 billion contract modification in the Navy's **Conventional Prompt Strike, CPS,** program. The contract is for the development of launcher systems and integration support onto Navy platforms. In August, the first **Zumwalt-class guided-missile destroyer** arrived in Mississippi for outfitting with CPS missiles and launcher systems as part of a $155 million contract with **Huntington Ingalls Industries**. Another program, the **Long-Range Hypersonic Weapon**, experienced delays. The **U.S. Army** had planned for this counterpart to CPS to be fully operational and deployed by the end of September, but a joint Army/Navy flight test in March was scrubbed reportedly due to a battery malfunction. Additional flight testing is scheduled prior to deployment.

The **U.S. Department of Defense** continued to prioritize the development of hypersonic systems, however, some programs received critical reviews from military leadership. Air Force Secretary Frank Kendall in March told a congressional committee that the service would conclude the **Air-Launched Rapid Response Weapon**, after an unsuccessful test earlier that month. Another flight test was conducted in August, but the Air Force did not publicly disclose the results. The Air Force is also working on the **Hypersonic Attack Cruise Missile**, an air-breathing, air-launched hypersonic missile. **RTX** of Virginia, formerly Raytheon Technologies, received the HACM contract in 2022. **DARPA** and the **Air Force** awarded $81 million to **RTX** in June for the **More Opportunities with the Hypersonic Air-breathing Weapon Concept** program, to continue maturing technologies for hydrocarbon scramjet propulsion. In March, the Navy awarded **Lockheed Martin** and **RTX** a combined $116 million to develop initial concepts for the **Hypersonic Air Launched Offensive Anti-Surface** weapon system, which is intended to be a follow-on to the **LRASM subsonic cruise missile**. In July, the Army demonstrated a new midrange capability strike developed by the **Army Rapid Capabilities and Critical Technologies Office** by ground launching **Tomahawk** cruise missiles and **SM-6** missiles from a new **Typhon Weapon System** delivered by Lockheed Martin. This launcher provides a capability of striking targets that fall between the ranges of the ATACMS short-range ballistic missile and the LHRW intermediate-range missile.

At much lower speeds, the Defense Department is investing in **electric aircraft** and **drones**. These technologies have demonstrated capabilities in the field and are being pursued under various programs. ★

▼ In March, the U.S. Navy and Missile Defense Agency launched a medium-range ballistic missile target from the Pacific Missile Range Facility in Hawaii. Two SM-6 missiles intercepted the target in the test, the Flight Test Aegis Weapon System 31 Event 1a.

Missile Defense Agency

Aviation management challenges increase

BY FRANK L. FRISBIE

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.

The year began with guarded expectations based on concerns about **FAA air traffic controller** staffing and airline crew staff capacity. Unexpectedly high travel demand exacerbated by poor weather across the U.S. exposed these concerns. The already daunting challenges to air traffic operations received a serious setback in early January when more than 11,000 flights were canceled or delayed because of a two-hour ground stop, prompted by an outage of the **FAA Notice to Air Missions system**.

The lack of runway incursion technology led to multiple close calls, stressing the importance of airport surface management. Among them was in January at **John F. Kennedy International Airport** in New York, in which a **Boeing 777-200** that was taxiing into position crossed an active runway that another passenger aircraft was using for its takeoff roll. The departing aircraft aborted its takeoff attempt and subsequently taxied to the gate.

In June, upwards of 11,000 flights were delayed or canceled in a single day because of severe weather or controller staffing issues. There were several days this year in which 9,000 flights were delayed or canceled across the U.S. after powerful storms ripped through parts of the country where many busy hubs are located. Public criticism was very strong throughout the period.

As the year progressed, the aircraft traffic management community recognized the imminent challenges in airspace management as new entrants, notably **Joby Aviation**, a California company that is developing all-electric air taxi for commercial passenger service. Joby received an **FAA Special Airworthiness Certificate** in June for the first aircraft built at its pilot production line, clearing the company to begin flight tests with this production prototype. Other air taxi manufacturers, including California-based **Archer Aviation** and **Wisk**, as well as Germany-based **Lilium,** are on a similar path. In the face of these developments, **FAA** in July published an **Advanced Air Mobility Implementation Plan** providing guidance and direction as this emerging segment moves into the National Airspace System in a big way. In the near term, the plan focuses on preparing for air taxi operations during the **2028 Summer Olympics**.

In late June, **Virgin Galactic** completed its first commercial suborbital flight, marking a major step for space tourism. This event brought focus to **FAA's Space Data Integrator**, the first of several new capabilities to track and share information about vehicles launching and reentering. FAA calls SDI an "operational prototype" that will "enable improved situational awareness and airspace management decision-making" to manage traffic around commercial space operations, as well as enable FAA to make rules and adjustments moving forward.

Unidentified aerial phenomena also added to aviation safety and national security concerns this year. There were 510 such sightings in 2022, according to a report issued by the **U.S. Office of the Director of National Intelligence** in January. During a July congressional hearing, witnesses testified that the government has withheld a large body of information about sightings not attributed to natural phenomena. More information may be learned from closed hearings and from Congress's proposed provisions on UAP in the fiscal 2024 National Defense Authorization Act.

In August, FAA acknowledged it was investigating about 4,800 pilots suspected of falsifying medical records, 60 of which posed a clear danger to aviation safety and were ordered to cease flying pending the outcome. Much of the oversight was attributed to faulty information exchange between the **Department of Veterans Affairs** and **FAA**.

Virtually all the challenges faced by civil aviation in the U.S. this year occurred without a permanent FAA administrator until late October, when the U.S. Senate confirmed Michael Whitaker to the position. ★

Contributor:
Charles Keegan

▼ Two members of the Italian Air Force and one engineer from the National Research Council of Italy rode in Virgin Galactic's VSS Unity spaceplane, pictured here, in June to an altitude of 85 kilometers. It was the first flight with paying customers for the suborbital service.

Virgin Galactic

Pieces are coming together for CFD Vision 2030

BY REYNALDO J. GOMEZ III, ANDREW W. CARY AND ANDREW M. 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.

Demonstrating efficiently scaled **computational fluid dynamics simulations** on an exascale system is a key technology milestone for the CFD Vision 2030 activity. The term "exascale" refers to a system capable of performing one exaflop, or 10^{18} floating-point operations per second. The **Frontier** system at the **Oak Ridge National Laboratory** in Tennessee passed acceptance testing in April, making it available to over 1,000 developers and researchers worldwide. **GE Aerospace** and the **FUN3D group at NASA's Langley Research Center** in Virginia are among the early users of this world-leading system, using it to attempt simulations that would have been impossible on previous systems. GE is using Frontier to assess aircraft engine design trade-offs, from the microscopic features of turbulence to the larger effects of how these flow features evolve and affect system performance and noise. NASA Langley researchers are pursuing simulations of long-duration reentry trajectories into the Martian atmosphere using retropropulsion to meet this key 2024 technology milestone. Located at the **Argonne National Laboratory** in Illinois, a second exascale-class system known as **Aurora** reached an important milestone in June when hardware installation was completed. Aurora is projected to provide a computational capacity exceeding two exaflops.

Improvements in computer speed and memory size are key enablers for simulating the complex flow fields around aircraft and spacecraft. To leverage these capabilities efficiently, improvements are needed for solver algorithms and post processing. The **AIAA CFD High Lift Prediction workshops** have included a growing number of higher-order solvers, highlighting the need for higher-order meshing and visualization. Fortunately, commercial developers are developing these capabilities. **Pointwise** from California-based **Cadence Design Systems** continues to improve its higher-order meshing, and Washington-based **Tecplot Inc**. released a new version of its **Tecplot visualization code** in August that includes support for high-order mesh elements.

Launchpad damage after the **SpaceX Starship** launch in April and the **Artemis I Space Launch System** launch in 2022 showed the harsh environments that launchpads must endure and the challenges associated with protecting them. Full-scale testing and analysis of these dynamic, chemically reacting, multiphase environments are major challenges. The **Launch, Ascent, and Vehicle Aerodynamics, LAVA, group** at NASA's Ames Research Center in California is working with **NASA's Exploration Ground Systems** in Florida to validate its code with the **Artemis I** flight data and develop new environments for **Artemis II** using tools that require high-performance computing, complex physical models and robust algorithms to understand these environments.

A key goal of AIAA's CFD Vision 2030 Integration Committee is to see leading-edge research moved into production codes that can benefit industry and government programs. An example of such progress is Bell's **V-280 tiltrotor**. Its selection last year as the **U.S. Army's Future-Long Range Assault Aircraft** was upheld in April by the U.S. Government Accountability Office after a bid protest by **Sikorsky**, whose coaxial rotor aircraft, the **Defiant X**, was turned down by the Army. The decision to select the V-280 for the Army's next major aircraft development program was informed in part by high-fidelity CFD/computational structural dynamics calculations the Army performed on both configurations. Specifically, since 2014 the **Army Combat Capabilities Development Command Aviation and Missile Center** has investigated the performance of both vehicles by performing calculations on the **Defense Department's High Performance Computing Modernization Program**'s massively parallel computer systems using the Computational Research and Engineering Acquisition Tools and Environments Air Vehicle, or **CREATE-AV**, **Helios** software. Scaled-model tests performed by the companies validated the accuracy of the high-fidelity models. ★

▲ This computational fluid dynamics simulation of a NASA Space Launch System rocket igniting was created by the Launch, Ascent, and Vehicle Aerodynamics, or LAVA, group at NASA's Ames Research Center in California.

NASA's Ames Research Center/Timothy Sandstrom

U.S. and Indian lunar missions headline the year's events

BY LEENA SINGH, NARAYANAN R. RAMACHANDRAN AND SURENDRA P. SHARMA

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

NASA flight engineers spent this year in extensive post-flight analysis of the **Orion** crew capsule components as part of the **Artemis I** mission to lunar orbit. Orion returned to Earth in December 2022. Although the spacecraft did not carry crew, it traveled with three instrumented humanlike payloads to help engineers characterize its handling qualities to better protect astronauts in future missions. Data showed the European-built service module generated 20% more power than expected and consumed 25% less power than predicted. NASA also scrutinized telemetry from the **Space Launch System rocket** that lofted Orion to orbit. Early analyses from onboard instrumentation showed that the four thrust and fuel/oxidizer ratios of the four **RS-25 engines** on the SLS core stage were within 0.5% of predicted values and that internal pressures and temperatures were within 2% of design. The flight, the first with the SLS design, also provided important data for the verification and validation of ground support equipment and critical assessment of flight phenomena such as suppression of coupled instability.

In April, **NASA and the Canadian Space Agency** announced the four astronauts for **Artemis II**, the first crewed mission to lunar orbit in 50 years: NASA astronauts **Reid Wiseman**, commander; **Victor Glover**, pilot; **Christina Hammock Koch**, mission specialist 1; and Canadian astronaut **Jeremy Hansen**, mission specialist 2. Artemis II is scheduled for launch in November 2024.

▼ India became the first country to land a spacecraft in the lunar south pole region in late August, when the robotic Vikram lander touched down. The lander carried the Pragyan rover, which rolled off the lander to explore the nearby terrain. Pragyan took this picture of Vikram via an onboard camera.

Indian Space Research Organisation

In September, NASA's **Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer, or OSIRIS-REx**, spacecraft built by Lockheed Martin made a close approach to Earth to release a capsule containing regolith samples from the asteroid Bennu. The capsule landed under parachutes in Utah, and OSIRIS-REx began its new mission to the asteroid Apophis, becoming OSIRIS-APEX.

NASA's **James Webb Space Telescope** continued to lift the veil on the mysteries of the universe. Webb's highly sensitive multimodal spectral sensors provided measurements previously only theorized. Scientific research teams analyzing Webb's views of the "El Gordo" galaxy cluster published papers in July and August, identifying more remote galaxies seen through gravitational lensing, in which El Gordo magnified light from galaxies that are some 10.6 billion light years away. Webb's image showed a disk-shaped galaxy about a quarter the size of the Milky Way, with spectral information on its star-formation history. Other lensed galaxies show a red giant star, highlighting Webb's capabilities. Previously lensed discoveries from the **Hubble** telescope could only see down to blue supergiants, which are much more massive and observable.

In contrast, amateur astronomers in Japan participating in a backyard astronomy observation program detected a bright flash in Jupiter's atmosphere caused by asteroids or comets penetrating the planet's atmosphere. According to Ko Arimatsu, a Kyoto University astronomer running the program, the impact is estimated to be comparable to a 2-megaton TNT explosion. Citizen astronomers are valuable for such science because it is impractical to have high-value scientific apparatus dedicated to such chance events.

In August, India's **Vikram lunar lander** touched down on the lunar south pole, the country's first controlled landing at the moon. India's **Chandrayaan-3 spacecraft** was launched in July carrying the lander, and was inserted into lunar orbit in early August. Once in lunar orbit, Vikram separated for descent. On the surface, Vikram demonstrated its surface exploration capabilities with a short 30-centimeter hop. Vikram is equipped with a range of sensors, including a seismometer, a surface temperature probe and a robotic surveyor that has traversed about 100 meters from the lander. The lander and rover were designed to operate for one lunar day — about 14 Earth days. They were each deemed to have completed their mission in early September when they transitioned into sleep mode for the oncoming lunar night. ★

Pushing the boundaries of high-speed commercial travel

BY JULIET PAGE AND GÉRALD CARRIER

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.

▲ In June, NASA's X-59 aircraft was moved to the flight line at Lockheed Martin SkunkWorks' facility in Palmdale, California. NASA announced in October that it moved the first flight to 2024 due to "several technical challenges identified over the course of 2023."

Lockheed Martin

NASA made progress in its Quesst mission, which aims to deliver data defining community responses to quiet supersonic flight. In June, NASA's **X-59** research aircraft was moved from the construction site to the flight line at Lockheed Martin's Skunk Works in California for integrated power-on testing leading to first flight. This year, California-based **Crystal Instruments** delivered initial production versions of its autonomous, high-fidelity ground recording systems to NASA, which is preparing the units for a risk reduction field test, scheduled for the end of the year, near **Armstrong Flight Research Center** in California. The systems are to collect acoustic data from X-59 overflights. In October, NASA and its Harris Miller, Miller and Hansen-led contract team conducted a test of the survey methodology being developed for the Quesst community tests, including recruitment, survey administration and data processing.

In August, **SpaceWorks Enterprises** of Georgia released results of a NASA-sponsored high-speed commercial transportation market study assessing lifecycle modeling. The aircraft design space spanned cruise numbers between Mach 1.5 and Mach 5, maximum unrefueled operating range between 3,500 and 7,000 nautical miles, passenger counts between 20 and 50, and four fuel-type options. As part of this effort, SpaceWorks conducted a 2023 travel survey. Ticket price elasticity analysis showed that for trans-Atlantic flights, willingness to pay premium fares dropped significantly relative to the 2020-2021 study (post-covid-19), but trans-Pacific market demand remained comparable to pre-pandemic levels. Modeling demonstrated that Mach 1.5 business cases typically resulted in the lowest ticket prices, lowest aircraft prices, highest market capture and most aircraft sold. The addition of quick refueling stops for shorter-range aircraft improved the business case for higher cruise aircraft (Mach 3-5) but was insufficient to outperform lower-Mach aircraft flying direct. At NASA's fifth **High-Speed Commercial Vehicles Workshop** in August, SpaceWork's John Olds said that "the Earth isn't big enough to have a Mach 5 commercial aircraft" when considering taxi times, acceleration times and calculating actual time savings.

NASA awarded a combined $5.1 million across two contracts for the development of **high-speed conceptual designs** and **technology roadmaps**. **Northrop Grumman** received the first contract in January, and **Boeing** the second in May. The studies are part of NASA's efforts to explore the development of an integrated strategy for high-speed aircraft technology and establish sustainable civilian aircraft capable of flying at speeds of Mach 2 to Mach 5 by 2040. The contractors will design conceptual vehicles and provide them to NASA as reference vehicles. They will identify and present their best estimates and rationale for thresholds and goal values for metrics of interest for future civil certification. The designs will identify technologies and develop roadmaps addressing environmental, economic and societal barriers to sustainability. The Northrop Grumman team includes **Boom Supersonic** of Colorado, **Blue Ridge Research and Consulting** of North Carolina and **Rolls-Royce LibertyWorks** of Indiana. The Boeing team includes **Exosonic** of California, **Georgia Tech Aerospace Systems Design Laboratory**, **GE Aerospace** of Ohio and **Rolls-Royce LibertyWorks**.

A team led by the **University of Washington** with **Stanford University**, the **University of Michigan** and **Boeing** conducted several wind tunnel and water tunnel tests this year at the University of Washington's **Kirsten low-speed wind tunnel** and **Boeing's Flow Visualization Water Tunnel.** The tests were part of a NASA-funded study of supersonic configurations at low speeds. Low-boom shaping results in unique configuration features, such as very long slender noses and upper mounted nacelles, and **NASA's Supersonic Configurations and Low Speeds project** is investigating performance at low-speed takeoff and landing flight conditions. Areas of study include low-speed aerodynamics, stability and control, multidisciplinary design optimization, computational fluid dynamics, panel methods and supersonic transport conceptual design. ★

Contributors: *Peter Coen, David Lazzara, Todd Magee and Lori Ozoroski*

Advanced air mobility aircraft developers prepare for passenger service

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.

▲ Wisk in July flew its electric demonstrator Cora in public for the first time. The company says the remotely supervised flight, conducted at the EAA AirVenture show in Wisconsin, was the first public, autonomous flight of a powered-lift passenger aircraft.

Wisk

With the earliest targets for passenger flights aboard electric air taxis still some time away, developers of these aircraft, regulators and early adopters continued progress toward making advanced air mobility a reality.

In June, **Volocopter** flew its two-seat **VoloCity** for the opening flight demonstration of the Paris Air Show. The German company plans to ferry passengers in these **electric vertical takeoff and landing** aircraft during the 2024 Paris Olympics.

In the U.S., California-based **Archer Aviation** and **Joby Aviation** are targeting 2025 for beginning passenger flights. In early 2023, FAA began finalizing the criteria to type certify the Archer and Joby aircraft after receiving public comments on proposed **Special Class Airworthiness Criteria** in late 2022. Joby and Archer also received increases in their contracts with the **U.S. Air Force's Agility Prime program**, which is paying Joby up to $131 million and Archer up to $142 million to each deliver multiple aircraft to Air Force bases. Air Force, FAA and NASA personnel will evaluate their utility for carrying personnel and supplies for both military and civil applications. Joby delivered the first aircraft to **Edwards Air Force Base** in September.

In March, **BETA Technologies** of Vermont announced it would develop the **CX300**, a conventional takeoff and landing variant of its **Alia** eVTOL. The company is targeting 2025 for FAA type certification of the CX300, followed closely by Alia in 2026.

In May, **Boeing** announced that autonomous air taxi developer **Wisk** of California was now a wholly owned subsidiary after Kittyhawk Corp. sold its share of Wisk to Boeing. In July, Wisk conducted a remotely supervised flight of its **Cora** electric demonstrator at the **EAA AirVenture** air show in Wisconsin. Archer in August agreed to purchase Wisk's autonomy technology in the future, one of the terms of the settlement of a multiyear lawsuit in which Wisk alleged theft of trade secrets by Archer.

Also in August, an eVTOL prototype from U.K. eVTOL developer **Vertical Aerospace** crashed during a remotely piloted test flight. Vertical later determined the cause was a faulty propeller, which the company said it had redesigned for its next **VX4** prototype prior to the crash.

In June, **FAA** released proposed rules for certifying early pilots and permitting commercial operations of **powered-lift eVTOLs** — those that would cruise on nonrotating wings and use propulsive lift for slow flight, including vertical takeoff and landing. Industry comments on the **Special Federal Aviation Rule** expressed concern that the proposed regulations were overly conservative. The public comment period closed Aug. 14.

In response to the **Advanced Air Mobility Coordination and Leadership Act** that Congress passed last year, the U.S. government formed an **AAM Interagency Working Group**, which in May released a request for information for public comments on developing a "National Strategy for AAM." The working group, comprising 22 federal departments and agencies, plans to deliver this strategy in 2024.

In the **regional air mobility** sector, several companies are seeking FAA certification for autonomous systems for small cargo aircraft. In April, **Xwing** of California submitted to FAA the certification plan for its **Superpilot** flight control hardware and software, which the company plans to install on **Cessna Caravans** for remotely piloted operations. In July, **Reliable Robotics** of California announced that FAA had accepted the certification plan for its system. Also in July, **Merlin Labs** of Massachusetts announced it had conducted 25 autonomous cargo demonstration flights in Alaska with its **Merlin Pilot** hardware and software.

In March, California-based **Universal Hydrogen** conducted the first hydrogen-powered flight of its modified **Dash 8** aircraft, in which one of the aircraft's turboprop engines was replaced by a New York-based **Plug Power's** hydrogen fuel cell and Washington-based **magniX's** electric motor. Universal Hydrogen plans to sell kits to retrofit regional aircraft to run on hydrogen fuel cells. ★

READ THE APPRECIATION

ALEX STOLL, A LEADER IN THE FIELD OF EVTOLS

U.S. government studies, hearings highlight increasing awareness of UAP as an aerospace safety concern

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 UAP.

BY PATRICK DONOVAN

In recent years, the U.S. Defense Department, NASA and Congress, among other government agencies, have officially stated that **unidentified anomalous phenomena, UAP**, represent a safety of flight issue and may pose a challenge to U.S. national security. This year, there was a dramatic increase in efforts and actions by the U.S. government, academia and the private sector to address UAP as an aerospace safety concern.

In January, the **U.S. Office of the Director of National Intelligence** released the report, "2022 Annual Report on Unidentified Aerial Phenomena." It documented a large increase in the number of **reported UAP incidents** since the previous year — 144 to 510. This increase could be a sign of increased UAP activity, an increase in reporting and data collection efforts, a reduction in the topic's stigma or some combination of these factors. The report concludes that "UAP continue to represent a hazard to flight safety and pose a possible adversary collection threat."

The **2023 National Defense Authorization Act**, or NDAA, that President Joe Biden signed into law in December 2022 further strengthened mandates on the Defense Department, including the establishment of new requirements to develop procedures to synchronize and standardize the collection, reporting and analysis of UAP incidents; to conduct scientific, technological and operational analyses of UAP data; and to supervise the development and execution of a science plan to develop and test, as practicable, scientific theories regarding UAP. In July, the **National Security, the Border, and Foreign Affairs subcommittee of the House Committee on Oversight and Accountability** held a hearing on UAP sightings and their implications on national security. Three witnesses — including committee chair **Ryan Graves**, a former U.S. Navy pilot who has reported UAP encounters — discussed the continuing stigma that they believe prevents pilots from reporting UAPs and the lack of follow-up or concern by their superiors. In August, Rep. Tim Burchett, R-Tenn., formed the bipartisan **UAP Caucus**. Burchett and other caucus members have called for the creation of a selection committee on UAP and asked House leadership to hold classified hearings on the topic.

Also in July, the U.S. Senate passed its version of the **2024 NDAA**, containing multiple, far-reaching provisions related to UAP. Among them was an amendment put forward by Senate Majority Leader Chuck Schumer, D-N.Y., and Sen. Mike Rounds, R-S.D., the **"UAP Disclosure Act of 2023,"** which requires the public release of all U.S. government records related to UAP, pending a review by a selected panel. This pending legislation may enable the analysis of previously unattainable sensor data by the various civilian scientific efforts existing today. As of November, the House of Representatives had yet to pass its version of the NDAA.

In September, **NASA's UAP Independent Study Team, UAPIST**, held a press briefing and released a report that acknowledged the aviation safety risk that UAP represent and the need for scientific study. The report concluded with a recommendation "that NASA play a prominent role in the whole-of-government effort to understand UAP by leveraging its extensive expertise to contribute to a comprehensive, evidence-based approach that is rooted in the scientific method."

In the private sector, Graves in February formed the nonprofit **Americans for Safe Aerospace** to raise awareness of UAP as an aviation safety and national security issue. As of November, the organization had amassed some 8,500 members. ASA is one of a number of academic and private sector organizations studying and aiming to raise awareness of UAP, including the Galileo Project at Harvard University and Enigma Labs based in New York City.

Further illustrating the growth of civilian efforts, **AIAA's Aviation Forum** in June included a technical panel session on UAP for the first time, with eight papers presented. ★

▼ NASA's Unidentified Anomalous Phenomena Independent Study Team, UAPIST, held a public meeting in May at NASA Headquarters in Washington, D.C. Chaired by David Spergel, at far left, UAPIST in September released a report that recommended, among other actions, a "whole-of-government effort to understand UAP."

NASA/Joel Kowsky

Skydweller Aero of Oklahoma converted the piloted Solar Impulse 2 solar-powered aircraft for autonomous test flights early this year.

Skydweller Aero

Uncrewed and remotely piloted vehicles set records in civil and military worlds

BY MICHAEL S. FRANCIS

The **Unmanned Systems Integration Committee** represents and serves the broad interests of the unmanned and robotic systems community, encompassing space, aerial, ground, surface water, underwater, and other unmanned and robotic systems, their components, and their \myriad applications.

In July, a U.S. Air Force's **XQ-58A Valkyrie** demonstrator, developed by AFRL and Kratos Defense and Security Solutions, executed aerial combat tasks in flight commanded by **artificial intelligence software** — an aviation first. Its **machine learning-based algorithms**, trained over millions of datasets in a simulated environment, were developed by the **Air Force Research Laboratory** prior to the flight. The Valkyrie is a potential contender in the forthcoming **Collaborative Combat Aircraft program** announced in March by Air Force Secretary Frank Kendall. His plan would acquire and pair at least 1,000 CCAs with piloted **Next Generation Air Dominance fighters**, with development to begin in fiscal 2024. CCAs are being developed to achieve performance comparable to contemporary piloted aircraft and are expected to be significant force multipliers.

International conflicts including Russia's war on Ukraine continued to highlight the many roles for uncrewed and remotely piloted aircraft in military operations. These ranged from intelligence, surveillance, reconnaissance and targeting to lethal combat, with aircraft supplied from external partners on both sides of the conflict.

In February, **Skydweller Aero** announced it had completed the first fully autonomous flight demonstrations with its uncrewed, solar-powered aircraft. The Oklahoma company's "mega-endurance" aircraft is an optionally piloted version of the **Solar Impulse 2**, an experimental plane that in 2015 became the first aircraft to make an around-the-world flight on solar power. Upgraded with a human-rated fly-by-wire system, the aircraft flew in Spain autonomously from takeoff to landing, although a safety pilot was on board.

Small drones continued to expand their presence in domestic and international civil and commercial markets. In August, **Walmart** announced a partnership with drone developer **Wing** (an Alphabet company) to expand deliveries in the Dallas area to an additional 60,000 homes. In a September blog post, Wing said it delivers "upwards of 1,000 packages a day" with its fixed-wing, hydrogen fuel-cell-powered drones. In July, **New York City** released new regulations to increase operations of uncrewed aircraft, including drones in all five boroughs, and the state's Power Authority approved the first funding for a planned $37.2 million program to expand use of drones for infrastructure inspection.

In October, **EHang's two-seat EH216-S** became the first fully autonomous, **electric vertical takeoff and landing aircraft** to receive a type certificate. Its approval by the **Civil Aviation Administration of China** paves the way for EHang to begin commercial service, initially for aerial tourism and sightseeing.

In September, **FAA** delayed the implementation of its **Remote Identification** rule by six months. This regulation requires all drones greater than 0.55 pounds (249 grams) flown by hobbyists or for business purposes to continuously broadcast their identity, location and flight state. In addition to bolstering security for drone operations, this capability could prove essential for future air traffic management.

At July's **EAA AirVenture** air show, in Oshkosh, Wisconsin, Boeing subsidiary **Wisk** flew its all-electric **Cora demonstrator**, the first public flight of an autonomous, electric vertical takeoff and landing aircraft. The emerging **advanced air mobility** market is focused on developing cost-competitive, short-range aircraft that provide alternatives to terrestrial vehicles including buses, taxis and cargo trucks. Wisk plans to begin passenger flights with uncrewed, remotely supervised air taxis in the late 2020s.

In the space industry, **SpaceX** in November flew a **Falcon 9** booster for the 18th time, a record for the most flights by a rocket stage. The booster lofted a batch of **Starlink** satellites to orbit, then fired its retrorockets to autonomously land on the deck of the drone ship landing platform. ★

Contributors: *Brian Argrow, Jamey Jacob and Kevin Kochersberger*

Celebrating 50 years since the launch of Skylab and other anniversaries

BY MICHAEL MACKOWSKI

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

May 14 marked the 50th anniversary of the launch of **Skylab**, the first U.S. space station. Plans had called for the inaugural crew of astronauts to launch 24 hours later, but damage to the spacecraft's micrometeoroid shield and solar arrays shortly after liftoff prompted NASA to delay that launch. After being launched to the station on May 25, the astronauts made a series of on-orbit repairs during their 24-week stay, the first of three long-duration crewed missions to Skylab. This year, commemorative celebrations were held between May and September at **Space Center Houston** in Texas, the **U.S. Space and Rocket Center** in Alabama, the visitor complex at **NASA's Kennedy Space Center** in Florida and the **Museum of Flight** in Seattle. Multiple online events and lectures on the Skylab program were also hosted throughout the year.

Several events recognized other historical moments in space exploration. In May, the **Space Museum and Grissom Center** in Missouri held its annual Show Me Space event. The theme was "Women in Space" and featured several female astronauts and pioneering aerospace engineers. The event highlighted the history of female astronauts and stories from the designers of early crewed spacecraft and included readings from a new children's book, book signings and guest lectures. In July, the **Gus Grissom Boyhood Home** museum in Indiana hosted its Galactic Gathering, honoring the contributions of astronauts from the state. The event was held in Mitchell, the hometown of Apollo 1 astronaut Gus Grissom, and his brother and son attended.

The U.S. National Park Service's National Center for Preservation Technology and Training held the **Preserving the Race for Space Symposium** in June. The conference in Cape Canaveral, Florida, highlighted challenges and accomplishments of the preservation of space exploration facilities and artifacts. Attendees included conservators, curators, cultural resource managers, scientists, engineers and collection owners. Attendees were given tours of NASA Kennedy and Cape Canaveral Space Force Base, which included NASA's Vehicle Assembly Building and original Vanguard launchpad and blockhouse.

In April, **Boeing** opened a new home for the vast Boeing archives. Company historian Michael Lombardi and his team moved to a former 747 assembly building in Auburn, Washington, which now houses documents and artifacts going back to the earliest days of the company.

June 25 marked the 100th anniversary of the first demonstration of **air-to-air refueling** via a hose and valve system. Flying over Rockwell Field in San Diego, a modified DH-4B pumped gasoline to a second DH-4B flying below. This development enabled an October flight that was the first nonstop north-to-south crossing of the U.S.

June 26 was the 75th anniversary of the start of the **Berlin Airlift**, in which the U.S. and British air forces delivered food and supplies to Allied-controlled west Berlin after the Soviet Union blockaded the roads. In 278,000 flights between June 1948 and September 1949, aircrews delivered 2.3 million tons of coal, food and other supplies, initially with **C-47s** and other aircraft and later with four-engine **C-54s**. To mark the anniversary, the exhibition, "Blocked Victors — Divided Berlin: 75 Years of the Airlift," opened in June at the Tempelhof Airport in Berlin.

In other anniversaries, Aug. 1 marked 100 years since the first test flight of the **DB-1B**. This day bomber was the U.S. Army's first all-metal, thick-wing experimental monoplane, primarily built of duralumin. ★

Contributors: *Jonathan Coopersmith, Deborah Douglas, Walter Gordon and Kevin Rusnak*

▼ The final crew of NASA's Skylab took this photo of the lab from their command and service module after they departed in November 1973 to return to Earth. The lone solar array at right was manually deployed by the first Skylab crew earlier that year; the other array was torn off shortly after the station was launched in May.

NASA

NASA astronaut Frank Rubio in September set a new record for longest spaceflight by an American. He spent a little over a year aboard the International Space Station.

NASA

A year of breaking ground: moon landings, asteroid samples and diverse spaceflight crews

BY AMIR S. GOHARDANI

The **Society and Aerospace Technology Outreach Committee** promotes the transfer and use of aerospace technology for the benefit of society.

With many space missions in the works this year, a few made historic impact.

In April, NASA announced the crew of its **Artemis II** mission, scheduled for late 2024: NASA astronauts Victor Glover, Christina Koch and Reid Wiseman and Canadian Space Agency astronaut Jeremy Hansen. This crew contains several firsts: Glover will be the first Black astronaut to orbit the moon and Koch the first woman. Hansen will be the first Canadian astronaut to participate in a lunar mission.

In August, India's **Vikram** lander touched down near the lunar south pole for the **Chandrayaan-3** mission, making India the fourth country to land a robotic craft on the moon — the United States, China and the former Soviet Union being the first three.

Days after the landing, a **Crew Dragon Endurance** capsule was launched toward the **International Space Station** with the most internationally diverse crew of any SpaceX launch to date. The crew consisted of mission commander Jasmin Moghbeli, a NASA astronaut; European Space Agency astronaut Andreas Mogensen; Japanese astronaut Satoshi Furukawa; and Russian cosmonaut Konstantin Borisov. The four crew members are scheduled for a six-month stay on the station.

September was an eventual month. **Frank Rubio** broke the record for the longest spaceflight by a NASA astronaut, spending 371 days aboard ISS. The previous record of 355 days was set in 2022 by Mark Vande Hei. Rubio's record was not planned. He arrived at ISS in September 2022 with two Russian cosmonauts for a six-month mission. In December, their Soyuz capsule developed a coolant leak, prompting NASA and Roscosmos to extend their stay as the leak was studied. Roscosmos later determined that a meteoroid struck the capsule and in February sent a replacement Soyuz to the station to bring the three crew members home.

Also in September, NASA's **OSIRIS-REx** spacecraft returned to Earth orbit to release a capsule filled with rocks and dust from the asteroid Bennu. That capsule touched down under parachutes at the Utah Test and Training Range, making the U.S. the second nation after Japan to collect samples from an asteroid and return them to Earth. Short for Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer, OSIRIS-REx is an opportunity for scientists to learn more about the time when the sun and planets formed about 4.5 billion years ago. Scientists plan to study the Bennu samples for insights into how Earth acquired the ingredients that made life possible.

A week before the OSIRIS-REx landing, Amazon Studios released **"A Million Miles,"** the story of NASA astronaut **Jose Hernandez**. Born in Mexico, Hernandez and his siblings helped his farm-working parents pick produce in the fields of the San Joaquin Valley in California. The movie tells the story of how Hernandez's dream of the stars led him to become a NASA astronaut. He applied to the program 12 times before being accepted in 2004. After completing his training in 2006, Hernandez supported space shuttle launches as a mission control capsule communicator at NASA's Kennedy Space Center in Florida. In 2009, he flew as a mission specialist aboard the space shuttle Discovery in **STS-128**, the 30th shuttle mission to ISS. ★

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

FEATURED EVENT

8–12 JANUARY 2024

Orlando, FL

AIAA SciTech Forum is the world's largest event for aerospace research, development, and technology. Thousands come to witness breakthrough science, revolutionary technologies, and next-generation capabilities that are redefining what is possible in aerospace. Immerse yourself in a wealth of information and leave with fresh ideas and new perspectives to elevate your work.

aiaa.org/SciTech/program/why-attend

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2024			
6–7 Jan	2nd AIAA High-Fidelity CFD Verification Workshop	Orlando, FL (aiaa.org/scitech)	
6–7 Jan	Design of Experiments Course	Orlando, FL (aiaa.org/scitech)	
6–7 Jan	Propeller Aerodynamics for Advanced Air Mobility Course	Orlando, FL (aiaa.org/scitech)	
6–7 Jan	Spacecraft Design, Development, and Operations Course	Orlando, FL (aiaa.org/scitech)	
7 Jan	Hypersonics: Test and Evaluation Course	Orlando, FL (aiaa.org/scitech)	
8–12 Jan	AIAA SciTech Forum	Orlando, FL	25 May 23
10 Jan	AIAA Associate Fellows Induction Ceremony and Dinner	Orlando, FL	
16–25 Jan	Aircraft Maintenance Management Course	ONLINE (learning.aiaa.org)	
29 Jan–7 Feb	Mission-Based Vehicle Design Course	ONLINE (learning.aiaa.org)	
30 Jan–8 Feb	Cryogenic Fluid Management for Storage & Transfer of Liquid Propellants in Space Course	ONLINE (learning.aiaa.org)	
6 Feb–14 Mar	Vibration of Periodic Structures Course	ONLINE (learning.aiaa.org)	
13 Feb–7 Mar	Fundamentals of Aeroelasticity: From Basics to Application Course	ONLINE (learning.aiaa.org)	
14–15 Feb	ASCENDxTexas	Houston, TX	
21–22 Feb	Principles of Success in Spaceflight from Andrew Chaikin Course	ONLINE (learning.aiaa.org)	
26 Feb–3 Apr	Design of Space Launch Vehicles Course	ONLINE (learning.aiaa.org)	
2–9 Mar*	IEEE Aerospace Conference	Big Sky, MT (www.aeroconf.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.).

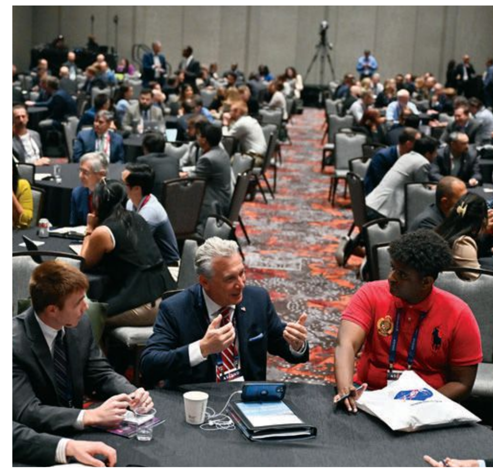
DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2024			
5 Mar	49th Dayton-Cincinnati Aerospace Sciences Symposium (DCASS)	Dayton, OH (aiaa-daycin.org/DCASS)	12 Jan
5–26 Mar	Financial and Business Acumen for Navigating the Aerospace Industry Course	ONLINE (learning.aiaa.org)	
11 Mar–17 Apr	Turbomachinery for Emerging Space Applications Course	ONLINE (learning.aiaa.org)	
19–28 Mar	Aircraft Reliability & Reliability Centered Maintenanc Course	ONLINE (learning.aiaa.org)	
19 Mar–18 Apr	Design Evolution of Aircraft Structures Course	ONLINE (learning.aiaa.org)	
25–27 Mar	Understanding Space: An Introduction to Astronautics & Space Systems Engineering Course	ONLINE (learning.aiaa.org)	
23–24 Mar	AIAA Region VI Student Conference	Santa Clara, CA	26 Jan 24
4–5 Apr	AIAA Region II Student Conference	Cape Canaveral, FL	4 Feb 24
5–6 Apr	AIAA Region III Student Conference	Akron, OH	9 Feb 24
5–6 Apr	AIAA Region IV Student Conference	Stillwater, OK	9 Feb 24
5–6 Apr	AIAA Region V Student Conference	St. Louis, MO	2 Feb 24
12-13 Apr	AIAA Region I Student Conference	Morgantown, WV	29 Jan 24
16–18 Apr	AIAA DEFENSE Forum	Laurel, MD	17 Aug 23
18–21 Apr	AIAA Design/Build/Fly	Wichita, KS (aiaa.org/dbf)	
8–10 May*	4th IAA Conference on Space Situational Awareness (ICSSA)	Daytona Beach, FL (http://reg.conferences.dce.ufl.edu/ICSSA)	
8–10 May*	Dayton Digital Transformation Summit	Dayton, OH	
14 May	AIAA Fellows Induction Ceremony and Dinner		
15 May	AIAA Awards Gala	Washington, DC	
4–7 Jun	30th AIAA/CEAS Aeroacoustics Conference	Rome, Italy (aidaa.it/aeroacoustics/)	8 Dec 23
12–14 Jun*	CEAS EuroGNC 2024	Bristol, UK (https://eurognc.ceas.org)	
29 Jul–2 Aug	AIAA AVIATION Forum	Las Vegas, NV	12 Dec 23
30 Jul–1 Aug	ASCEND Powered by AIAA	Las Vegas, NV	12 Dec 23
9–13 Sep*	34th Congress of the International Council of the Aeronautical Sciences	Florence, Italy (icas2024.com)	
14–18 Oct*	75th International Astronautical Congress	Milan, Italy (iac2024.org)	

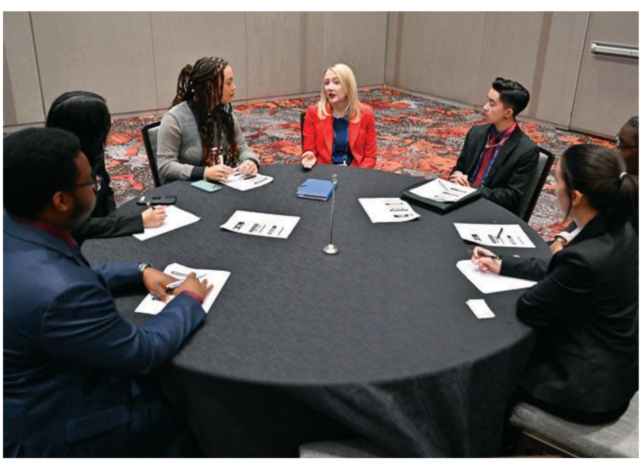
**Meetings cosponsored by AIAA. Cosponsorship forms can be found at aiaa.org/events-learning/exhibit-sponsorship/co-sponsorship-opportunities.*

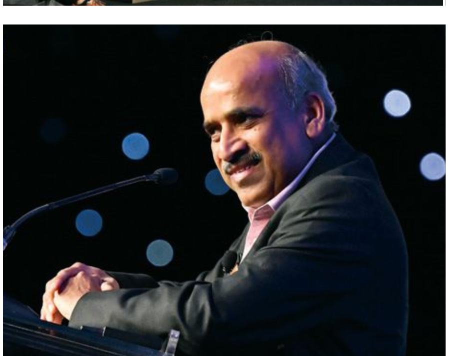
● AIAA Continuing Education offerings (green rows)

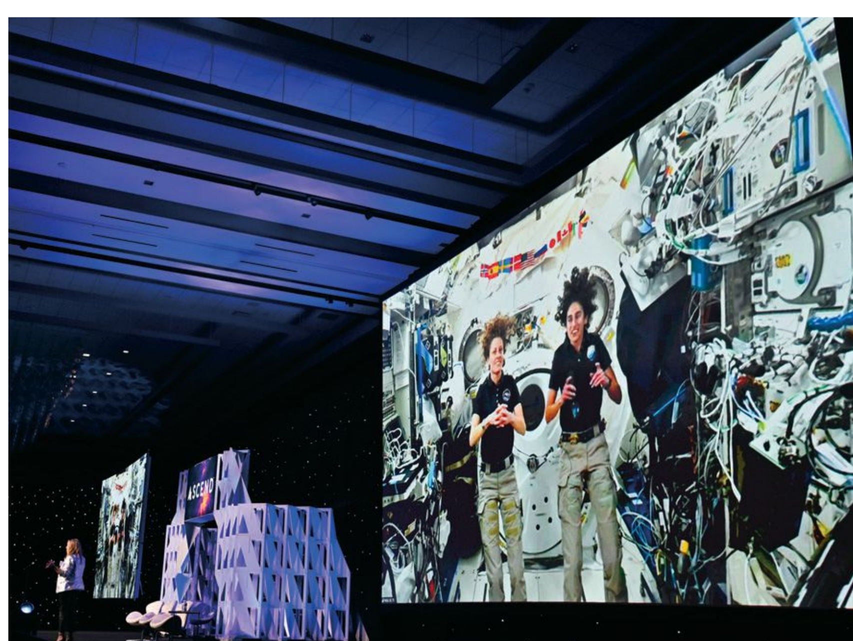
ASCEND

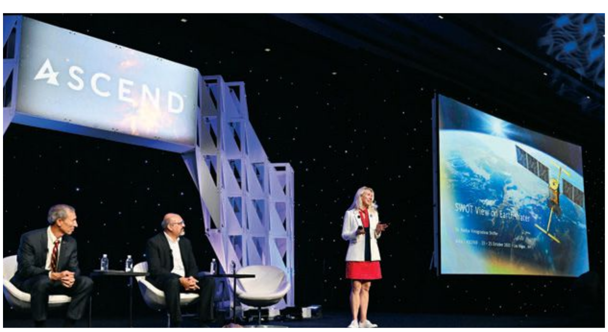
With nearly 1,600 attendees, 2023 ASCEND, held 23–25 October in Las Vegas, brought together a diverse cross-section of space's leading industry luminaries and thinkers, biggest companies, government leaders, educators and students, and serious enthusiasts. The event fostered collaboration and inspired business development to accelerate humanity's future in space.











Fourteen Diversity Scholars attended 2023 ASCEND thanks to generous sponsorship from The Boeing Company and the grant received from Blue Origin's Club for the Future. Of the group, 75% were first-generation college students, and 12 scholars were female or female-identifying. Scholars heard from industry leaders and participated in networking events where they made valuable connections with those leading the future of innovation in the commercial space sector. AIAA Diversity Scholar applications for the co-located 2024 AIAA AVIATION Forum/2024 ASCEND event are open through 2 May 2024. Learn more: aiaa.org/DiversityScholarsProgram.

MAKING AN IMPACT

Highlighting AIAA Educator and K-12 Programs

Trailblazing STEM Educators Attend Cape Canaveral Experience

In October, some of the 2022 and 2023 Trailblazing STEM Educator Award recipients were invited to attend two launches and receive behind-the-scenes tours at Cape Canaveral. Educators Kellie Taylor (Idaho), Caroline Little (Minnesota), and Aymette "Amy" Medina (Texas) participated in a VIP tour of Blue Origin's Manufacturing Complex where they got to see up close what goes into building a heavy-lift launch vehicle. On seeing the tools, workspace, and massive pieces of machinery, Ms. Medina noted, "It's like what my students are doing in the classroom with their rocket, but on a much larger scale." The group also toured the Kennedy Space Center Visitor Complex where they experienced interactive exhibits and activities that explored the past, present, and future possibilities of space exploration.

A trip to the Florida Space Coast wouldn't be complete without seeing a launch, and the awardees got to enjoy two — a night launch of a SpaceX Falcon 9 from a rooftop vantage point, as well as a daytime launch of a ULA Atlas V rocket from the Banana Creek viewing area at Kennedy Space Center.

Nominations for the 2024 Trailblazing STEM Educator Award are now open. The award includes $5,000 for the educator, $5,000 for their school or organization, a trip to Washington, DC, to be honored at the AIAA Awards Gala, and access to Challenger Center educational resources. Learn more and nominate an educator **by 15 December 2023** at **aiaa.org/trailblazing**.

The Trailblazing STEM Educator Award is presented by AIAA and Challenger Center. The launch trip was made possible thanks to the support of Blue Origin's Club for the Future.

In celebration of the great diversity of the aerospace industry, AIAA seeks to recognize its members with outstanding contributions to diversity, inclusion, and the advancement of the field. If you wish to nominate someone for this recognition, or if you wish to self-nominate, please fill out the form at aiaa.org/get-involved/committees-groups/Diversity-and-Inclusion/history-and-heritage-month-nomination-form.

AIAA and Club for the Future's Resilient Student Scholarship Launches

AIAA and Club for the Future have created a new **$10,000 scholarship** designed to empower and inspire students who have faced unique challenges. Individuals with disabilities, students from underrepresented racial and ethnic groups, gender minorities, individuals from disadvantaged backgrounds, and first-generation students are especially encouraged to apply.

Applicants must be a graduating high school senior enrolling in a STEM program at a U.S. college, university, or technical (e.g., two-year degree) program. Other requirements include AIAA high school membership (membership is free); a minimum GPA of 2.5; demonstrated interest in aerospace through extracurricular activities; and a short personal essay (500 words or fewer). Learn more: **aiaa.org/get-involved/k-12-students/scholarships**.

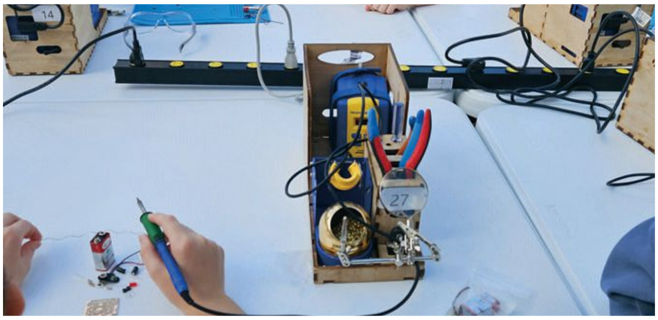
Award Presented at 2023 ICSSC

Paul Thompson, University of Surrey (retired), was presented with the 2023 AIAA Aerospace Communications Award at the 2023 Joint 40th ICSSC and 28th Ka and Broadband Communications Conference, held 24–27 October in Bradford, United Kingdom. Thompson was recognized for "exceptional service in satellite and space systems design, engineering, and international collaboration."

(L to R) Paul Thompson and Rabindra Singh, Axta Space Corporation and chair of the AIAA Communications Systems Technical Committee

MAKING AN IMPACT

Highlighting AIAA Educator and K-12 Programs



SmallSat Event Inspires Educators and Students from Around the World

The second annual SmallSat Education Conference was held 28–29 October at the Center for Space Education at Kennedy Space Center, FL. Three hundred fifty attendees – who came from all over the world – included educators, administrators, and students ranging from middle school up through postgraduate.

While the ages and level of experience varied, all attendees were united in their interest and passion for SmallSats, CubeSats, or high altitude balloons. The conference provided hands-on opportunities (including an outdoor session on intro to soldering) as well as workshops and speakers. A special presentation by Jon Arenberg (Chief Engineer – James Webb Space Telescope, Northrop Grumman) left the entire audience enthralled and motivated to accomplish remarkable feats.

AIAA student branches, sections, and Headquarters were all represented in the exhibit area, along with technical societies from Florida and beyond, STEM clubs and programs, high school robotics teams, and more.

The event was organized and managed by the AIAA Cape Canaveral Section, The Wolfpack CubeSat Development Team, the Aerospace and Innovation Academy, and the AIAA Palm Beach Section. Other sponsors included: Aerojet Rocketdyne Foundation; BLUECUBE Aerospace; the Satellite Educators Association; the IEEE Canaveral Section; Jacobs; Maru Space Technology; Missile, Space, and Range Pioneers; and Florida Tech. For more information, and to learn about future opportunities, visit **smallsateducation.org**.

AIAA is Pleased to Introduce the New AIAA Domain Leads

In October 2021, AIAA embarked on a new approach to accelerate innovation in three Domains across the aerospace industry: Aeronautics, Aerospace Research and Development, and Space. We have benefitted from leadership in each Domain by Ming Chang (Aeronautics), Scott Fouse (Aerospace R&D), and Julie Van Kleeck (Space). They have developed roadmaps and guided exploration and new initiatives with multiple AIAA volunteers and the AIAA staff. Their two-year tenure is closing and we now welcome new professionals to build additional momentum and extend the Domain roadmaps even further. It is with great excitement we introduce the new AIAA Domain Leads who are beginning their work in early December.

Aeronautics: Russell R. Boyce
Mission Assurance Pty Ltd
(AIAA Fellow)

Boyce previously served as Director of UNSW Canberra Space and was Professor and Chair of Hypersonics at the University of Queensland. Additionally, he has advised the MILO Space Science Institute and Australian Space Agency and chaired the Australian Academy of Science's National Committee for Space and Radio Science.

Aerospace Research and Development: Greg Zacharias
Pasteur Labs
(AIAA Senior Member)

Zacharias previously served as Chief Scientist for the Director of Operational Test and Evaluation, Office of the Secretary of Defense (2018–2021) and Chief Scientist of the United States Air Force (2015–2018). He was cofounder and later president of Charles River Analytics. He also has served on the National Research Council and the USAF Scientific Advisory Board.

Space: Brent Sherwood
Blue Origin (retired)
(AIAA Associate Fellow)

Sherwood recently retired from Blue Origin as Senior Vice President, Advanced Development Programs. Before joining Blue Origin, he held various positions at NASA Jet Propulsion Laboratory and The Boeing Company. Sherwood is a former chair of the AIAA Space Architecture Technical Committee.

We sincerely thank and acknowledge the hard work and many contributions of Scott Fouse, Julie Van Kleeck, and the late Ming Chang. As the inaugural group of AIAA Domain Leads, they have been instrumental in bringing this approach from concept to reality by tackling the critical issues confronting aerospace professionals and their organizations as they shape the future of aerospace. Please read more about the progress of each of the three Domains in the Flight Path column (**pages 6-8**).

Obituaries

Jim French: A Remembrance

by Michael D. Griffin

James R. "Jim" French Jr., a Fellow of both AIAA and the British Interplanetary Society, died on 6 October 2023. He would have been 87 in December.

After receiving his B.S. in Mechanical Engineering from MIT in 1958, Jim worked at what was then the Rocketdyne Division of North American Aviation on the development and testing of the H-1, F-1, and J-2 engines for the Apollo/Saturn launch vehicles, and from 1963 to 1967 at then-TRW on the Apollo Lunar Module descent engine, a record of contribution that includes most of the engines that took people to and from the moon. His memoir, *Firing a Rocket*, offers a personal reminiscence of those years as well as a treasure trove of hands-on rocket engineering experience that is captured nowhere else.

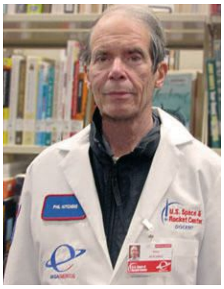
After joining NASA Jet Propulsion Laboratory in 1967, Jim participated in many pioneering interplanetary robotic space missions, including Mariner 5-9, Viking 1 and 2, and Voyager 1 and 2. He was the Chief Engineer for the SP-100 Space Nuclear Power Program, and led many advanced-mission studies including, most notably, the first credible design study for a Mars Sample Return mission.

Jim left JPL in 1986 for the position of Vice President–Engineering of the American Rocket Company, one of the earliest entrepreneurial space launch vehicle start-ups. From 1987 until his retirement, he was in private practice as a much-sought-after consultant in space systems engineering. Among other prominent roles, he was the government Chief Engineer for the DoD/NASA vertical takeoff, vertical landing, rapid-turnaround launch vehicle prototypes DC-X and DC-XA, and was a long-standing consultant on the development and operation of Blue Origin's New Shepard suborbital space tourism vehicle.

In addition to his memoir, Jim was the co-author of the best-selling textbook, *Space Vehicle Design*, and for over twenty years taught an AIAA short course based on that book. His six-decades of service to AIAA included chairmanship of both the Los Angeles Section and the AIAA Space Systems Technical Committee, as well as membership on several other AIAA technical committees. He was a recipient of the Shuttle Flag Award, the 2008 Summerfield Book Award, and was named Engineer of the Year by the AIAA Orange County Section.

Jim was in love with things that flew. He was a member of the California Wing of the Civil Air Patrol and an accomplished commercial pilot, owning and flying a variety of aircraft including a Citabria, a Cessna 205, and a Smith Miniplane. As an airframe and powerplant mechanic, credentials he somehow earned during whatever spare time he had in the Apollo years, he could also fix those airplanes.

On a more personal note, Jim was the person who showed me, and dozens of other young engineers, how to go about being a space systems engineer. He was intolerant of excess bureaucracy, process theater, hypocrisy, self-promotion, unqualified authority figures, and bigotry in any form. He did not suffer fools but was endlessly patient with those who were willing to strive. Our careers were linked across more than four decades; he was at various times my boss, my colleague, a consultant to my organization, my co-author, my teacher, and my student. Above all, he was always my friend. I will miss him until it is my turn to leave.



AIAA Senior Member Kitchens Died in September

Philip H. Kitchens, 78, died on 7 September.

Kitchens earned a degree in chemical engineering from Louisiana Polytechnic Institute in 1967. As graduation approached, Kitchen's father took him to hear a presentation by Wernher von Braun in Shreveport. Following his graduation, he was hired by Werner von Braun as a member of the team that developed the Saturn V rocket that carried the Apollo 11 astronauts to the moon in July 1969.

Among the missions that Kitchens supported were Apollo 8, Apollo 11, and Apollo 13. Kitchens earned a master's degree in mechanical engineering from the University of Alabama in Tuscaloosa in May 1971, before returning to NASA Marshall Space Flight Center. He later accepted positions with the EPA in Jackson, Mississippi, and the Ethyl Corporation in Baton Rouge before enrolling at Louisiana State University.

Kitchen went on to earn a master's in library science in 1976 and accepted a position in the engineering library at the University of Alabama in Tuscaloosa, where he became active in the Special Library Association. In 1981, he returned to Huntsville, working as a librarian at the Redstone Arsenal Technical Library until his retirement in 2003. From 2012 until 2023, he volunteered his time as a NASA Emeritus Docent at the U.S. Space and Rocket Center, educating and inspiring the many guests.

To encourage future scientists and engineers, Kitchens established and funded the Philip H Kitchens Endowment for Science and Technology Resources, as well as establishing a scholarship for the U.S. Space and Rocket Center's Space Camp. AIAA also acknowledges his generous memorial donation to the AIAA Foundation.

AIAA Senior Member Freeman Died in September

Marsha G. Freeman died on 20 September. She was 76 years old.

Freeman attended Queens College and Columbia University's Teachers College, where she received a master's degree in education in 1970. She taught in inner-city Detroit before her interests turned her toward aerospace. She joined the Fusion Energy Foundation and wrote hundreds of articles in *Fusion Magazine, 21st Century Science and Technology* magazine, and *Executive Intelligence Review*, where she became the technology editor. She also wrote three books: *How We Got to the Moon, the Story of the German Space Pioneers*; *Challenges of Human Space Exploration*, about the scientific work done by Russian cosmonauts and American astronauts on the Russian Mir space station, a predecessor to the ISS; and *Krafft Ehricke's Extraterrestrial Imperative*, reviving the work of one of the most creative and imaginative of the German space engineers, who came to the United States after World War II.

Freeman started writing about space when there were hardly any women involved in the genre. When giving tours as an accredited tour guide to school kids at the Air and Space Museum in Washington, DC, she always told the girls that space was gender-neutral. Freeman attended the first Space Shuttle launch in 1981 and interviewed the pilot, Robert Crippen. She also was privileged to attend the ceremony at the White House when Eileen Collins, the first woman to command the Space Shuttle, was presented to President Clinton.

From 1992, Freeman was a very active member of the International Astronautical Federation's History Committee, writing for them and speaking at their annual congresses and helping edit their annual journals. She was a member of the AIAA History Technical Committee from 2000 to 2005.

AIAA Associate Fellow Back Died in March 2022

Lloyd H. Back died on 21 March 2022. He was 89 years old.

Back served in the U.S. Army from 1951 to 1955. In 1962 after Back completed his Ph.D. in Mechanical Engineering and Fluid Dynamics at UC Berkeley, he worked at the Jet Propulsion Laboratory until his retirement in 1992.

His professional contributions spanned widely varying applications in science including rocket propulsion, heat transfer processes, helicopter rotor, and rocket nozzle design. Back was especially proud of his biomedical research in conjunction with the Cardiology Department at the USC School of Medicine and later work studying details of blood flow in human atherosclerotic coronary arteries and the effects of angioplasty. He received many career accolades and greatly appreciated the large number of collaborative scientists he worked with. Back lectured at Caltech and USC Medical School, taught engineering courses at UCLA, and had 193 peer-reviewed publications in prominent journals.

THE UNIVERSITY OF ALABAMA® | College of Engineering
Aerospace Engineering and Mechanics

FACULTY POSITIONS

The Department of Aerospace Engineering and Mechanics (AEM) and the College of Engineering at The University of Alabama invite applications for multiple tenure-track and tenured faculty positions at all ranks, including Assistant Professor, Associate Professor, and Professor.

Candidates with particular research emphasis and interests in the areas of aerospace structures & materials, high speed aerodynamics, space systems/flight, hypersonic systems, and additive and advanced manufacturing are of particular interest for one or more of these positions and thus are strongly encouraged to apply. The AEM department and College are looking to both: (1) add faculty who will build upon existing strengths in the Department, College, and University and (2) add faculty who will expand the scope of research within the department, College, and UA as a whole.

Candidates with prestigious achievements in their field and exceptional national and international reputations will be eligible for consideration for significant endowment support through appointment as an Endowed Shelby Distinguished Professor or Associate Professor.

The AEM Department has a sustained enrollment of 500 BSAE students and has recently appeared on the ASEE list of the top 20 BSAE producers in the nation. The Department also has an active MS and PhD program in Aerospace Engineering and Mechanics supporting both residential and distance education students with a total graduate enrollment of over 150 students. Major research facilities in the Department include a $2M commitment for a new 8 X 8 inch cross-section wind tunnel that can operate at Mach 1.3-3.8 and is equipped with a 10 inch Schlieren system and 2 axis sting balance; and $3M mechanical fatigue testing laboratory with mutliaxial, thermomechanical fatigue, high/low temperature, and component testing facilities.

Applicants must have an earned doctorate in Aerospace Engineering, Engineering Mechanics, or a closely related field from an accredited institution. Applicants should identify their specific area(s) of research interest in the cover letter that should accompany their application materials. Applications should include a full curriculum vitae (CV), a statement of research interests and plans with future goals, a statement of teaching interests, and a list of at least four professional references. Review of applications will begin immediately and continue until the positions are filled, with an expected start date of August 16, 2024. Electronic submission of application materials via The University of Alabama employment website is required (https://careers.ua.edu/jobs/search/college-of-engineering).

For additional information regarding The University of Alabama, the Department of Aerospace Engineering and Mechanics, or this search, please contact Dr. Mark Barkey, Professor and Head, Department of Aerospace Engineering and Mechanics, mark.barkey@ua.edu.

The University of Alabama is an equal-opportunity employer (EOE) including an EOE of protected vets and individuals with disabilities. Women and under-represented minorities are encouraged to apply.

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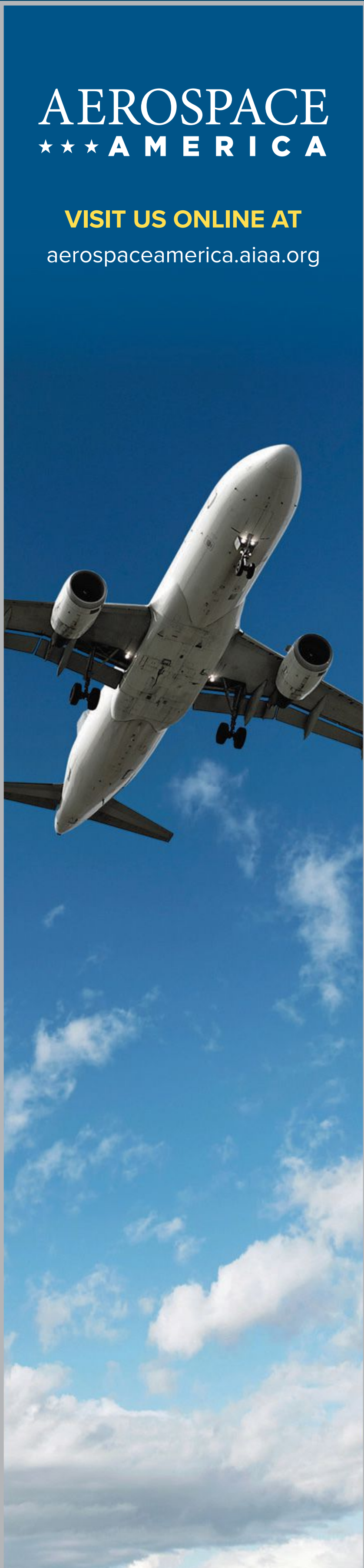

Assistant/Associate Professor in Mechanical and Aerospace Engineering

The Department of Mechanical and Aerospace Engineering (MAE) at New Mexico State University (NMSU) is searching for outstanding applicants to fill up to three (3) tenure-track faculty positions at the Assistant Professor or Associate Professor rank by Fall 2024 (Position number: 498818). Preference will be placed on applicants with research expertise in aerospace engineering such as

1) supersonic and/or hypersonic experimental aerothermodynamics,
2) materials and coatings for extreme environments, hot structures, and
3) guidance, navigation, and control of space systems, autonomy and robotics for space applications.

The candidates need to show potential to aggressively leverage opportunities at the state and federal levels, to develop and grow an impactful and sustainable research program, and to teach undergraduate and graduate level courses. The candidates should demonstrate a plan for successful collaborations with other faculty, both inside and outside NMSU, that fosters cross-disciplinary research.

NMSU is a land- and space-grant institution with a student population that exceeds 15,000. NMSU is classified by Carnegie as a Doctoral University with Higher Research Activity and as a Community Engagement institution with a large body of Hispanic and Native American students. The MAE department has strong undergraduate and graduate programs that continue to grow. The department offers B.S., M.S., M.E., and Ph.D. degrees in both Mechanical and Aerospace Engineering. Its location in Southern New Mexico is unique and puts the MAE department in close vicinity to the White Sands Missile Range, NASA-Johnson Space Center White Sands Test Facility, Sandia National Laboratories, Los Alamos National Laboratory, Holloman and Kirtland AFBs, and Spaceport America. The MAE department collaborates with the NMSU Physical Science Laboratory (a SCIF), which operates one of the largest FAA Flight Test Centers in the nation. Famous for the Organ Mountains-Desert Peaks National Monument and historic Mesilla, a healthy climate, and affordable and safe living, Las Cruces with its strong Southwestern culture is an attractive choice to build a successful career.

Responsibilities of an MAE Assistant/Associate Professor include:

- Developing an internationally-renowned, externally and competitively-funded, independent research program,
- Teaching and developing undergraduate and graduate-level courses,
- Advising students at undergraduate and graduate levels, and
- Participating in MAE shared governance processes and service activities.

The positions are for a 9-month appointment that will include a competitive salary and startup package. Academic rank and salary will be commensurate with the candidate's prior experience and qualifications. All offers of employment are contingent upon verification of the individual's eligibility for employment in the US and upon the successful completion of applicable background reviews.

Required Qualifications:

- Ph.D. in Aerospace or Mechanical Engineering, or a closely related field,
- Proven capacity or clear potential to successfully secure competitive research funding,
- Demonstrated ability to produce scholarly archival publications,
- Expression of a strong dedication to undergraduate and graduate-level teaching, and
- Commitment to inclusiveness for all students in teaching, learning, and advising.

Applications must be received by January 14, 2024, for full consideration. Review of applications will continue until the positions have been filled. Applicants should submit the following documents: (1) cover letter, (2) curriculum vitae, (3) teaching interests and philosophy statement (2 pages max.), (4) research plan (4 pages max.), and (5) the names and contact information for three professional references.

Applications are to be submitted electronically via **https://careers.nmsu.edu/jobs/search**

The position number is 498818.

USC Viterbi
School of Engineering
Department of Aerospace and Mechanical Engineering

The Department of Aerospace and Mechanical Engineering (https://ame.usc.edu) in the USC Viterbi School of Engineering invites applications for tenure-track or tenured faculty positions at all levels in all disciplines of Aerospace or Mechanical Engineering, with particular interests in (1) Energy and Sustainability and (2) Robotics and Autonomous Systems, including candidates whose research integrates Artificial Intelligence / Machine Learning into these disciplines. Candidates whose research has applications to any aspect of Aerospace Engineering are particularly welcome. The USC Viterbi School of Engineering is committed to increasing the diversity of its faculty and welcomes applications from women; individuals of African, Hispanic and Native American descent; veterans; and individuals with disabilities.

Successful candidates are expected to develop a world-class research program within a stimulating interdisciplinary environment and demonstrate a strong commitment to teaching at both the graduate and undergraduate levels. Priority will be given to the overall originality and promise of the candidate's research work.

Positions are available starting August 16, 2024. Applicants must have earned a Ph.D., or equivalent, degree in Aerospace or Mechanical Engineering or a related field by the beginning of the appointment. Applications must include: a cover letter; curriculum vitae detailing educational background, research accomplishments, and work experience; a research plan; a teaching and service plan; and contact information of at least four professional references. Applicants are also required to include a succinct statement on fostering an environment of diversity and inclusion. To receive full consideration, candidates should apply on-line at https://ame.usc.edu/facultypositions/, and all materials **should be received by January 8th, 2024**, although earlier application is encouraged; applications received after this deadline might not be considered.

The annual base salary range for the following faculty ranks in this posting are:

- Assistant Professor: $110, 250 - $131,250
- Associate Professor: $131,250 - $162,750
- Professor: $168,000 - $236,250

When extending an offer of employment, the University of Southern California considers factors such as (but not limited to) the scope of responsibilities of the position, the candidate's work experience, education/training, key skills, internal peer equity, federal, state and local laws, contractual stipulations, grant funding, as well as external market and organizational considerations.

The USC Viterbi School of Engineering is committed to enabling the success of dual career families and fosters a family-friendly environment. USC is an equal opportunity, affirmative action employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, protected veteran status, disability, or any other characteristic protected by law or USC policy. USC will consider for employment all qualified applicants with criminal histories in a manner consistent with the requirements of the Los Angeles Fair Chance Initiative for Hiring ordinance.

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knew about the globally agreed-upon GEO disposal guidelines created by the Inter-Agency Space Debris Coordination Committee long before FCC incorporated this requirement into its legal licensing.

The DISH case also points to a need for global transparency about who is or isn't compliant with GEO disposal. To that end, my research group at the University of Texas at Austin has developed the GEO disposal Compliance Assessment Monitor, or GEO-CAM. This software plumbs the orbital records aggregated and curated in our online ASTRIAGraph database. Users can go to an associated website and get a demo of this capability, which provides records of 100 compliant and noncompliant GEO satellites. Currently, FCC mainly relies on operators to self-report the end-of-life disposal of their satellites, and once a satellite is disposed of, the operator no longer pays a regulatory fee to FCC for that satellite. FCC monitors broader trends through publicly available data, such as the European Space Agency's annual GEO satellite report. The difference with GEO-CAM is that regulators could use it to monitor orbits independently and dynamically based on multiple sources of information and on a daily basis, instead of annually.

Also, fines for noncompliance should not be looked at as punitive in nature, but rather as preventative. We stand at a critical juncture where the establishment of a robust and stringent regulatory framework is essential to ensure responsible space object disposal — in the EchoStar-7 case, to a designated graveyard orbit. The objective must be for companies and organizations to not only adhere to space debris mitigation regulations but also to actively prioritize and invest in practices that safeguard the space environment for the benefit of future generations. Fines can serve as powerful incentives, encouraging companies to embrace effective practices and contribute to a cleaner, safer and more sustainable space environment.

The bold step taken by FCC should inspire regulatory bodies worldwide to follow suit and hold those out of compliance accountable. Only through unified action and a collective commitment to responsible space behavior can we hope to mitigate the growing menace of space debris and ensure that outer space remains accessible and secure for all of humanity. Let this fine be the catalyst for a brighter, cleaner future in the cosmos. ★

LOOKING BACK

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN

1923

1 **Dec. 13** Pioneer aviator Lawrence Sperry crashes his Sperry Messenger in the English Channel. His body is recovered four weeks later. The inventor of devices including the automatic stabilizer and landing skid, Sperry was flying from England to France to observe progress in aeronautics and to demonstrate his Messenger plane. An engine failure of some kind is later determined as the likely cause of the crash. **Aviation**, Dec. 24, 1923, p. 777.

Dec. 17 The 20th anniversary of the Wright brothers' flight is celebrated in their hometown of Dayton, Ohio. Many prominent figures in aviation visit the city, meeting with Orville Wright and touring McCook Field and Orville Wright Field. In the afternoon, a fleet of airplanes flies over the Wright home to demonstrate the advances in aircraft design since the 1903 flight. During an evening meeting, Adm. William Moffett of the U.S. Navy's Bureau of Aeronautics and Maj. Gen. Mason Patrick of the U.S. Army Air Service laud the Wrights for their contribution to civilization, and citizens of Dayton present a plaque to Orville. **Aviation**, Dec. 31, 1923, p. 803; **NASM**, biographical files.

Dec. 21 The French airship Dixmude goes down with 52 aboard off the coast of Sciacca, Sicily. The last of the former German naval airships transferred to France after World War I, Dixmude had recently set an endurance record of 118 hours, 41 minutes over the Sahara. Three days before the crash, the airship departed Toulon and flew southwest. Radio reports cited violent storms over the Sahara, and the reports ceased on Dec. 21. The wreckage found later indicates that the ship was struck by lightning and exploded. Douglas H. Robinson, **The Zeppelin in Combat 1912-1918**, p. 345; **Flight**, Jan. 10, 1924, p. 9; March 6, 1924, p. 113.

Dec. 27 World-renowned engineer Alexandre Gustave Eiffel dies at 91 in Paris. The constructor of the Eiffel Tower, he published his first book on aerodynamics in 1907. His famous book, "The Resistance of the Air and Aviation," was published in French in 1911 and translated into English in 1913 by Jerome Hunsaker. **Flight**, Jan. 3, 1924, p. 4.

Also during December Following successful experiments by the General Electric Co., the U.S. postmaster general announces that all U.S. airmail planes will carry radio sending and receiving sets so that pilots may keep in continual communication with ground stations during flight. **Aviation**, Dec. 10, 1923, pp. 704-5.

1948

Dec. 14 The Daniel and Florence Guggenheim Foundation announces the establishment of jet propulsion centers at Princeton University and Caltech to train engineers and scientists in rocketry and astronautics. These centers continue a long philanthropic tradition of the Guggenheim Foundation in U.S. aeronautical education. **Aero Digest**, January 1949, pp. 5, 70; NASA, **Aeronautics and Astronautics 1915-1960**, p. 61.

Dec. 17 The Smithsonian Institution unveils the reassembled Wright Flyer during ceremonies attended by U.S. President Harry Truman, relatives of the Wright brothers and many foreign dignitaries. The aircraft had been at England's Science Museum for 20 years because of a dispute with the Smithsonian; the institution claimed that its former secretary, Samuel Pierpont Langley, had designed the first heavier-than-air craft capable of sustained flight. The Smithsonian later recanted its error and in 1942 reached an agreement with Orville Wright to return the Wright Flyer to the United States for display at the Smithsonian's National Air Museum in Washington, D.C. **Aviation Week**, Dec. 13, 1948, p. 16.

Dec. 19 Hawker Siddeley test pilot Trevor Wade sets a London to Paris flight record in the first P.1052 prototype, completing the 350-kilometer trip in 21 minutes, 20 seconds. Wade had conducted the inaugural flight of this swept-wing transonic research aircraft a month prior. The P.1052 has a 35-degree swept wing with a span of 9 meters and can reach speeds up to 1,405 kph in level flight. BAE Systems, **Hawker P.1052 webpage**. William Green and Roy Cross, **The Jet Aircraft of the World**, p. 90.

Dec. 29 The U.S. Department of Defense's Research and Development Board releases a report stating that the United States has been engaged in research on artificial Earth satellites. An appendix to the report states, "The Earth Satellite Vehicle Program, which was being carried out independently by each military service, was assigned to the Committee on Guided Missiles for coordination." NASA, **Aeronautics and Astronautics, 1915-1960**, p. 61.

2 **Also during December** Northrop test pilot Charles Tucker completes the first flight of the experimental X-4 semi-tailless transonic research aircraft. During the flight at Muroc Dry Lake, California, the X-4 remains aloft for 18 minutes but does not exceed an altitude of 11,000 feet. Two X-4s are built, and the second is flown from 1950 to 1953 for a joint U.S. Air Force/National Advisory Committee for Aeronautics research program on stability and control. They conclude that the semi-tailless configuration is not suitable for transonic military fighters. **NACA X-4 Progress Report**, Jan. 6, 1949; **Aviation Week**, Dec. 27, 1948, p. 13.

Also during December The U.S. Navy announces flight testing of the Martin Gorgon IV. This radio-controlled, ramjet-powered missile is air launched from a Northrop P-61 Black Widow aircraft. The Gorgon, powered by a Marquardt ramjet engine, has a wingspan of 3 meters, a length of 6.5 meters and weighs 725 kilograms. The missile flies for 10 minutes during testing at the Naval Air Missile Testing Center in Point Mugu, California. **Aviation Week**, Dec. 6, 1948, p. 16.

Also during December The Piasecki Helicopter Co. reports that the first known helicopter loop occurred inadvertently during company tests with the XJPH-1 prototype. During a 2.5-g pullout test, the pilot simultaneously applied full-aft cyclic stick and full-up collective pitch. The XJPH-1 pulled out and up into a loop, arching over and encountering 4.16-g loads during the recovery. The helicopter, designed only to withstand 2.75-g loads, did not suffer structural failure, and the pilot landed the craft without incident. **Aviation Week**, Dec. 27, 1948, p. 11.

1973

Dec. 3 NASA's Pioneer 10 becomes the first spacecraft to reach the vicinity of Jupiter. The probe flies by at a distance of 130,000 kilometers, taking high- and low-resolution images of Jupiter and three of its largest moons: Callisto, Ganymeda and Europa. A New York Times editorial on the achievement notes that the flyby occurs after some 350 years of scientific study of Jupiter, and the data inaugurates "a qualitatively new stage of man's knowledge of this giant planet and his understanding of how its physical and other properties relate to the larger problem of the origin of the solar system and of the universe." **NASA Program Office**, December 1973. **New York Times**, Dec. 4, 1973, p. 42.

3 **Dec. 3** U.S. President Richard Nixon confers the rank of four-star admiral on retired U.S. Navy Vice Adm. Hyman Rickover in a White House ceremony in recognition of Rickover's outstanding leadership in developing the breakthrough technology that led to the Polaris, Poseidon and Trident submarine-launched ballistic missiles. **National Archives and Records Service's Weekly Public Information Office.**

Dec. 6 Concorde 201, Air France's first Concorde supersonic airliner and the first production model, makes its inaugural flight from Toulouse, France. The aircraft, piloted by Aerospatiales' André Turcat, reaches Mach 1.57. **Concorde Bulletin**, Jan. 12, 1974.

Dec. 7 Sir Robert Watson-Watt,

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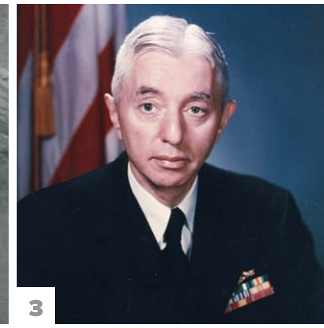

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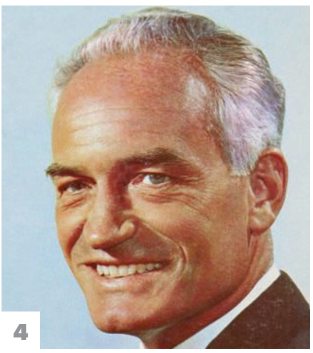

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Britain's "father of radar," dies in Scotland at 81. Watt is credited for directing and accelerating the development of radar immediately preceding World War II. He is best known for his pioneering work in the use of radio waves to detect aircraft; he also developed an underwater detection system to identify German U-boats during the Battle of the North Atlantic. **Washington Post**, Dec. 7, 1973, p. C15.

Dec. 10 NASA's Kennedy Space Center requests bids from 50 construction firms for a planned 6,600-meter runway on which space shuttle orbiters will land. The runway, which is to be constructed northwest of the Vehicle Assembly Building, is the first facility built in reshaping Launch Complex 39 for its coming role in the space shuttle program. **Kennedy Space Center** Release 7-74.

Dec. 14 A NASA twin-engine C-45 Beechcraft light aircraft flies from the Redstone Arsenal in Alabama, the first flight in a series to study geological phenomena and water quality. The aircraft is equipped with multispectral cameras to obtain multispectral photography of three sites in Alabama to investigate water resources, agriculture, land resources, ecology and archaeology. The flights also support the Earth Resources Technology Satellite and the Skylab Earth resources experiment package. **Marshall Space Flight Center** Release 73-201.

4 **Dec. 15** U.S. Sen. Barry M. Goldwater receives the Wright Brothers Memorial Trophy at a Washington, D.C., dinner commemorating the 70th anniversary of the Wright brothers' 1903 flight in Kitty Hawk, North Carolina. During World War II, Goldwater served in the U.S. Army Air Force and spent most of the war flying supplies to war zones in several countries under the Ferry Command. Following World War II, he was a leading proponent of creating the U.S. Air Force Academy and co-founded the Arizona Air National Guard. As a U.S. senator in the 1960s, he was instrumental in pushing the Pentagon to support the desegregation of the armed services. **Washington Post**, Dec. 15, 1973, p. D1.

Dec. 15 U.S. President Richard Nixon issues a proclamation calling for nationwide observance of Wright Brothers Day on Dec. 17, in honor of the 70th anniversary of the first powered flight. NASA, **Aeronautics and Astronautics, 1973**, p. 348.

Dec. 17 Scientist Charles Greeley Abbot, the fifth secretary of the Smithsonian Institution, dies in Washington, D.C., at 101. A physicist who specialized in solar energy, Abbot was a devoted supporter of the work of U.S. rocket pioneer Robert H. Goddard. In the 1910s, Abbot secured Goddard a grant from the Smithsonian to fund his earliest experiments with rockets. **Washington Post,** Dec. 18, 1973, p. B11.

Dec. 18 Cosmonauts Maj. Pyotr Klimuk and Valentin Lebedev are launched into low-Earth orbit for the Soyuz 13 mission. With NASA's Skylab 4 crew aboard the U.S. space station, this is the first time that the U.S. and the Soviet Union have crew orbiting Earth simultaneously. Among the objectives, Soyuz 13 is to observe stars in the ultraviolet range and study Comet Kohoutek, along with testing improved manual and automatic controls and methods of autonomous navigation systems. The cosmonauts also conduct biological experiments and study natural resources of Earth. On Dec. 26, the crew lands southwest of Karaganda, Kazakstan, despite a snowstorm and cylconic winds. **New York Times**, Dec. 21, 1973, p. 56.

Dec. 24 This is the fifth anniversary of the Apollo 8 crew's Christmas Eve reading from the Book of Genesis. NASA broadcasted the reading, conducted in lunar orbit, to TV and radio audiences that included one of every four persons on Earth. **Washington Star-News**, Dec. 24, 1973, p. A-1.

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5 **Dec. 4** NASA's space shuttle Endeavour is launched from Kennedy Space Center in Florida for STS-88, the first shuttle flight to the International Space Station. The orbiter carries the U.S.-built Unity module, which the crew is to attach to the Russian-built Zarya already in orbit. Two days later, the U.S. and Russian crew aboard Endeavour attach the two modules via shuttle's robotic arm, as well as cameras and computers to position the units into place. NASA, **Aeronautics and Aeronautics: A Chronology, 1996-2000**, p.p. 175-176.

Dec. 11 NASA's Mars Climate Orbiter is launched by a Delta IIT. The spacecraft carries several British instruments designed to measure weather and water content, as well as study dust. MCO is to arrive at Mars roughly the same time as the Mars Polar Lander, launched in January. Upon nearing Mars, MCO fires its engines for the orbital insertion burn, but signal is lost. NASA later determines that commands were sent to the orbiter in English rather than the required metric measurements, so the spacecraft's trajectory was off and it likely burned up in the Mars atmosphere. A year later, NASA loses contact with the Mars Polar Lander as it descends toward the Mars surface and concludes that the lander crashed. **Aviation Week**, Nov. 15, 1999, pp. 31-32, and Dec. 13, 1999, pp. 34-36.

6 **Also during December** NASA completes initial low-altitude flight testing with the solar-powered Centurion at Dryden Flight Research Center in California. The remotely piloted craft, built by AeroVironment, has 14 distributed propellers. NASA later flies the craft at altitudes up to 100,000 feet. **Flight International**, Dec. 16-22, 1998, p. 24.

Fining DISH Network for debris sets a necessary precedent

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The fine that DISH Network has agreed to pay for failing to move one of its geosynchronous television satellites to an assigned graveyard orbit marks a crucial turning point in the effort to spur space operators to act responsibly when their satellites approach the end of their lives.

The amount of the fine, $150,000, is not the main reason this is a turning point. Rather, it's the pioneering aspect of it: "This marks a first in space debris enforcement by the Commission," the U.S. Federal Communications Commission said in announcing the October settlement. Declaring the action as a "first" suggests that there will be other enforcement cases, making the DISH fine a precedent that hopefully signals a growing commitment among governmental and regulatory bodies to address the space debris issue and hold entities accountable for their actions.

The development couldn't have come sooner. The danger of catastrophic collisions is undeniable in a space environment with nearly 500,000 pieces of debris larger than 1 centimeter. The peril extends from geosynchronous equatorial orbit (GEO) 36,000 kilometers above the equator, down to low-Earth orbit — home to the International Space Station, a beacon of international scientific research and cooperation in space, as well as the Chinese space station.

Historically, the satellite industry has largely operated under a self-regulatory framework for debris mitigation. One repercussion of that leniency was the case of EchoStar-7. DISH relegated the satellite to an orbit a mere 122 kilometers above its operational orbit, rather than to a minimum altitude of 300 km above that orbit, as specified in the orbital debris mitigation plan in DISH's license, according to FCC. Such negligence not only endangers active satellites but also highlights the dire need for measures against noncompliance. We should also use this example to create a marketplace for space insurance companies to aid in driving space operators toward increased safety, security and sustainability.

DISH reportedly argued that EchoStar-7 was grandfathered out of the FCC's requirement for a minimum disposal orbit. Setting aside the legal intricacies of that argument, all operators

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