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AEROSPACE
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2019
YEAR IN REVIEW

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Astronauts Christina Koch, left, and Jessica Meir made history in October when they made the first all-female spacewalk. Page 75.
NASA

THE YEAR IN REVIEW

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

ON THE COVER
Stratolaunch, the world's largest aircraft by wingspan, flew for the first time in April. Pages 4, 33, 36.

AEROSPACE
★ ★ ★ AMERICA ★ ★ ★

DECEMBER 2019, VOL. 57, NO. 11

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MANUFACTURING AND DISTRIBUTION
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Aerospace America (ISSN 0740-722X) is published monthly except in August by the American Institute of Aeronautics and Astronautics, Inc., at 12700 Sunrise Valley Drive, Suite 200 Reston, VA 20191-5807 [703-264-7500]. Subscription rate is 50% of dues for AIAA members (and is not deductible therefrom). Nonmember subscription price: U.S., $200; foreign, $220. Single copies $20 each. Postmaster: Send address changes and subscription orders to Aerospace America, American Institute of Aeronautics and Astronautics, at 12700 Sunrise Valley Drive, Reston, VA, 20191-5807, Attn: A.I.A.A. Customer Service. Periodical postage paid at Reston, Virginia, and at additional mailing offices.

SHAPING THE FUTURE OF AEROSPACE

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An unsatisfactory test flight poses a question. Do you have the answer?

▲ The Stratolaunch aircraft touches down after its first flight.
Stratolaunch

Unfinished business

This year displayed a tantalizing mix of technical breakthroughs, human achievements and also vulnerability.

Six months after the death of its sponsor, billionaire Paul G. Allen, the Stratolaunch aircraft became the largest plane (by wingspan) ever to fly when pilots lifted off from Mojave Air and Space Port in California.

The video is amazing, but wowing us isn't why Allen, the Microsoft co-founder and self-proclaimed "Idea Man," formed Stratolaunch Systems Corp. eight years ago. He wanted to prove that satellite launch costs could be slashed by carrying launch vehicles and satellites to an altitude of 35,000 feet and boosting them from there. This would prepare the way for "world-altering" satellite applications, to use the company's words.

Still unclear is whether the Stratolaunch flight was the start of a new way of business or something that will be remembered as an engineering feat with little long-term significance, akin to the first flight of Howard Hughes' Spruce Goose in 1947. The company issued a dryly worded statement in October saying it had "transitioned ownership" to a person or entity it did not name.

In another case of unfinished business, neither of NASA's Commercial Crew contractors managed to launch a crew to the International Space Station this year. SpaceX's uncrewed launch to ISS and Boeing's pad abort test, deemed acceptable by NASA, suggest that 2020 could be the year we see this achievement.

And of course there is the matter of the Boeing 737 MAX aircraft and the accidents that killed 346 people. As of this writing, the FAA had yet to bless an update to the Maneuvering Characteristics Augmentation System anti-stall software and the planes remained grounded.

I believe it will take more than the MAX aircraft returning to flight in 2020 to achieve closure on this issue. An independent panel of some kind should be convened with the gravitas and authority of the Rogers commission that examined the space shuttle Challenger accident or the Columbia Accident Investigation Board. The many engineering, business and regulatory lessons from this saga should be recorded for those in business today and for posterity. ★

Ben

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

Reactions to "Mystery sightings"

I really enjoyed the "Mystery of the 'Damn Things'" article [November cover story]. I was interested when news broke a couple of years ago and was wondering what happened since then. Great reporting.

Michael Martin, AIAA senior member

I have read a lot of material about these Navy pilot incidents, and this is one of the best treatments I have seen. I especially appreciated the succinct critiques of various theories, as well as the quotes from some technical experts not previously heard from on this subject in anything I've read.

There was one paragraph, however, that bothered me a tad. Your use of the term "conspiracy theories" has a somewhat pejorative ring. The genesis of UFO theories in the late 1940s and 1950s was that a hell of lot of people were seeing the "damn things," including a great many military personnel (up to generals), especially at nuclear sites, as well as commercial pilots, private aviation pilots, knowledgeable people like Kelly Johnson*, and other credible witnesses. As for the CIA's claim that U-2 flights accounted for many UFO sightings, this has been refuted in detail by various researchers, including veteran UFO skeptic Robert Sheaffer and UFO photoanalyst Bruce Maccabee.

That aside, commendations on a solid piece of journalism on a thorny topic.

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*Clarence "Kelly" Johnson founded Lockheed Skunk Works and provided a UFO account to the U.S. Air Force's "Project BLUE BOOK" report.

In the 1990s, I gave two AIAA papers** involving UFOs based upon concurrent information and available photographs. The Aerospace America article was quite thorough and informative, especially about broaching speculations of Russian and Chinese capabilities, but did not address several important pieces of interest for engineers and scientists.

- At least one craft went from high to low altitudes within seconds and performed unusual maneuvers. Conventional wisdom implies biological beings, if they were on-board, could not survive the G-forces unless the craft offered no inertia. That would be a nice trick to obtain.
- Data tends to imply one craft reached orbital speed while it was flying near the ground, up to Mach 20. Another nice trick! For those with knowledge about hypersonics, the heating would be so severe to stress our known expertise where the survival of the craft would probably exceed temperatures above tens of thousands of degrees Fahrenheit. This craft must have generated a lot of thermal energy. In all of these events, there were no gas dynamic shocks or waves. That by itself pushes the credibility of conventional wisdom.
- One craft moves underwater at speeds of more than several hundreds of miles per hour. The best technology that we can establish underwater at high speed involves cavitating torpedoes that move on the order of 150 mph, none of which can perform underwater maneuvers because the saltwater dynamic pressure would easily destroy the structure. This UFO craft seems to be invulnerable to such effects.

These events demonstrate technologies beyond our competence. We should not be afraid of unknown knowledge that potentially offers us embryonic technologies which would exceed our imagination pinioned by the conventional wisdom. Instead, we, especially in academia, should spend significant and serious efforts to accept and develop this game-changing expertise and its promise to benefit humankind as we try to touch the stars.

P.A. Murad, AIAA associate fellow, Vienna, Virginia, ufoguypaul@yahoo.com

** "An Electromagnetic Rocket Stellar Drive....Myth or Reality? Part I- Electromagnetic and Relativistic Phenomenon," July 1995.
"An Electromagnetic Rocket Stellar Drive....Myth or Reality? Part II- Fluid Dynamic Interactions and an Engine Concept," July 1995

The Future of Autonomous Flight: The Technology Clock Ticks On

My family immigrated to the United States in the late 1800s in pursuit of the American dream. Leaving the European system of dictated standing of wealth, they dreamed of a land where they could come from nothing and become anything. The dynamic system of America offered hope that the fruits of their aspirations and hard work could be harvested.

My generation was raised during the Cold War with an eye on the Doomsday Clock counting down to the man-made global catastrophe of nuclear war or climate change. Our nation was in a technology-driven race to prevent the existential threat to our life, our liberty, and our dreams. The space race was the inspiration for my career in aerospace.

With the end of the Cold War, the threat receded and a new one emerged. In his 30 April 1992 speech to the Aero Club of Washington, D.C., Mr. A. D. Welliver, CTO of The Boeing Company, introduced a new clock, the Technology Clock. This clock represented our economic security and a countdown to the loss of U.S. leadership in aerospace.

A quarter of a century later, we are in an era of technology disrupters to our society, the aerospace community, and the global balance of power. A tipping point offering the promise of societal as well as environmental benefits is occurring from the confluence of social trends, technological advancements, and military and commercial interests.

Uncrewed and autonomous flight provides an example of the confluence of disruptive technologies which, in their infancy, are already providing social and economic benefits. Delivery of medical supplies to remote areas, search and rescue, and remote monitoring of critical infrastructure are only a few examples. I look forward to the day I can fly over Seattle's congested traffic!

The technical challenges to building this future include creating a safe transition for these vehicles into the operation of the airspace system, and defining the regulatory framework for replacing the current human-centric pilot and controller functions. The implementation of a regulatory foundation for emerging technologies requires 1) a clear framework and classification for the apportionment of risk to the aviation system components for the varying degrees of automation vs autonomous learning systems, 2) clarity of the contribution of deterministic systems (the machine) and non-deterministic systems (the pilot) to safety, 3) clarity of the safety level required for various degrees of autonomy and for new technologies, and 4) validation of the methods used to ensure compliance.

While our members and key stakeholders have made tremendous progress toward addressing the challenges, a remark by NASA Administrator Charlie Bolden at the 2013 AIAA AVIATION Forum hints at our biggest challenge. He commented that he would like to see the aviation community more active, noting "If I got half the pressure from this community that I get from one Congressman on going to a distant planet, we'd be OK." His comment strikes at the heart of the speedbump to realizing the full potential of autonomous flight: we lack a common intent.

Realizing the full potential of uncrewed and autonomous flight is a shared responsibility of government, academia, infrastructure providers, operators, manufacturers, and suppliers. Our community must come together to engage policymakers to assure they understand what must be done, what is at risk, and what R&D and infrastructure investments must be made to complete the foundation for uncrewed and autonomous flight.

The unifying strength of our members' shared values and their technical leadership roles uniquely position AIAA to bring the stakeholders together. These values include:

- **Collective and Collaborative Capabilities:** There is strength and reason in diverse disciplines.
- **Knowledge Excellence:** Intellectual pursuit requires education and learning to expand upon current thought.
- **Challenge and Excitement in the Work:** We desire to make a difference.
- **Honor and Achievement:** We must promote the value of the profession to the public.
- **Future Vision:** We believe in the importance of what we do, and that there is ever more work to be done.

As the Doomsday and Technology Clocks march toward midnight, imagine the day where a rising nation announces that they have tethered an uncrewed vehicle to their latest fighter. Then imagine how the balance of power begins to shift.

The price for losing our technical leadership will be high: loss of jobs, a declining economy, and a shift in the balance of power. We must start the conversation with policymakers on how this generation will come together to drive the confluence of technology disruptors to address societal concerns and to assure the dream is passed to the next. ★

James Vasatka
Member, AIAA Board of Trustees

AERO PUZZLER

Do you have a puzzler to suggest? Email us at **aeropuzzler@aiaa.org.**

Flight-test feedback

Q. After landing, a test pilot says the prototype jet was difficult to control in certain configurations and wanted to stall sooner than it should. He assesses "a Cooper-Harper of 7 to 8" at times. One of the engineers sighs: "Well, it was worth a shot, but we'd better put them back on." What devices is the engineer most likely referring to, and why would it be desirable to leave them off?

Draft a response of no more than 250 words and email it by midnight Dec. 9 to aeropuzzler@aiaa.org for a chance to have it published in the January issue.

FROM THE NOVEMBER ISSUE

CANARD CONUNDRUM: We asked whether Rafale fighters and NASA's X-59 low boom design have canards for the same reason. NASA's Mark Guynn and Clint Balog of Embry-Riddle Aeronautical University helped us select the winning response:

WINNER: False. The Dassault-built Rafale fighter is a two-surface airplane which utilizes the canard for pitch stability and control. The X-59 is a three-surface airplane and uses the canard to redistribute the lifting surface area for the purpose of reducing the sonic boom made during supersonic flight. Most aircraft's wings create lift aft of the aircraft's center of gravity (CG) which results in a negative moment. Therefore, an additional lifting surface is required to balance the moments in the pitch-axis. In conventional aircraft, a tail is used to create negative lift and a positive moment. In the case of the Rafale fighter, the trailing-edge of the wing is already at the back of the plane. The designers utilize a lifting surface forward of the CG to balance the moments to maintain pitch stability while giving controllability in the pitch-axis with changing the canard's incident angle.

The three-surface design utilized by the X-59 allows the wing to be smaller due to the canard providing lift. Also, the canard helps reduce the size of the horizontal tail because the forward-of-CG lifting surface would require a smaller aft lifting surface to balance the moments. By redistributing the cross-sectional area of a wing and tail along the fuselage, the designers may be able to achieve a quieter sonic boom. Loud sonic booms are a result of shock waves building up from different surfaces of an airplane. By redistributing the cross-sectional area, the shock wave buildup can be reduced.

Royd Johansen
AIAA member
San Jose, California
Johansen is an aeronautical engineer for Northrop Grumman.

For a head start ... find the AeroPuzzler online on the first of each month at https://aerospaceamerica.aiaa.org/ and on Twitter @AeroAmMag.

Materials that remember show promise for aircraft and space applications

BY DARREN J. HARTL

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

Morphing missiles being explored by the U.S. Air Force Research Laboratory would adjust their shapes in flight to provide aerodynamic benefits. Such concepts are enabled by novel actuator designs and morphing skins.
U.S. Air Force Research Laboratory

New applications of shape memory materials were demonstrated worldwide this year, while new morphing structural concepts were tested in new ways.

Boeing and NASA's Glenn Research Center in Ohio tested **shape memory alloys, or SMAs,** that could be incorporated into the composite materials that form the components of **deployable structures on commercial airplanes**. These SMA compositions would respond autonomously to ambient temperature changes. The new NASA-Boeing SMAs were incorporated into the hinge of a deployable vortex generator that was flight-tested on a Boeing 777-200 in November as part of the company's **ecoDemonstrator program**. The vortex generator retracts at cruise to reduce drag.

At the same time, Texas A&M University researchers worked with University of British Columbia to develop **SMA artificial muscle actuators** mimicking the functionality of characterized **bird muscles**. Results were first presented publicly in May, showing that SMA components can act as actuators, brakes and structural components under cyclic stimuli, emulating avian muscle functions.

In July, the **Harbin Institute of Technology** in China revealed the existence of an experimental satellite that tested a prototype shape memory polymer composite for **self-deploying solar arrays, or SMPCs**. In a paper in the journal Smart Materials and Structures, the designers of the experiment, called Mission SMS-I, described the mission as the **first SMPC demonstration in geostationary orbit**. The authors said they have proved that their carbon-reinforced SMPC can deploy solar arrays by direct harvesting of solar energy without drawing system electrical power. To increase the stiffness of the solar array, new SMPC-based structures were studied this year toward the goal of a second round of flight testing, according to the authors.

A number of new wind tunnel demonstrations of aeronautical adaptive structures applications were also performed this year. To quantify for the first time experimentally the acoustic benefit of an SMA slat cove filler in transport aircraft, researchers from Texas A&M University and NASA's Langley Research Center in Virginia deployed a **new aeroacoustic wind tunnel** at Texas A&M in February and recorded a 2 decibel noise reduction at 20 meters/second on a 6.25% scale wing model. An international team from Boeing, Deharde, the European Transonic Windtunnel and Langley demonstrated a **new wind tunnel testing paradigm** allowing airplane models to be actuated in a cryogenic wind tunnel, even given small model feature sizes. The test article consisted of a 4.5% scale Boeing-787 half-model with **control surfaces powered by fully integrated SMA rotary actuators**. In August, the model was tested at cryogenically simulated flight Reynolds number conditions. Another collaborative project initiated this year by the University of Maryland, University of Bristol and Intelligent Automation Inc. with NASA support demonstrated the feasibility of a **camber morphing wing prototype**. The prototype consisted of multimaterial 3D-printed morphing skins supported by a 3D-printed bioinspired flexure. The prototype's 60-centimeter camber morphing section was actuated in a 24 m/s free jet wind tunnel with minimal flutter. Upscaling and flight tests are planned for future phases.

Regarding noncommercial applications of adaptive structures, in September, the Aerospace Systems Directorate of the Air Force Research Laboratory first demonstrated a **multiphysical "dry tunnel"** that creates a simulated aerothermal test environment for morphing missiles. The approach gives researchers uninterrupted access to the structurally adaptive test article during simulated flight testing for full field strain and temperature tracking and allows testing of various missile articulation mechanisms across a range of speed and altitude conditions not achievable in traditional wind tunnels.

University of Central Florida researchers funded by the U.S. Navy's Office of Naval Research this year explored **transient fluid-structure interactions** during sea-based air vehicle morphing to find optimal configurations for modular high-stiffness structures. The researchers measured the unsteady forces on a twisting and bending compliant wing via water towing tank experiments, validating the concept and enabling new modeling approaches. ★

Novel designs and NASA's moon-to-Mars goals inspire next generation

BY LISA SAAM

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

▲ **A bird-of-prey-inspired** design that Airbus says will motivate the next generation of aeronautical engineers to create sustainable aircraft.
Airbus

Airbus in July released the conceptual design for a new airliner that it said would push the boundaries of technology and innovation with its birdlike appearance. Revealed on the opening day of the Royal International Air Tattoo air show in the United Kingdom, the design was dubbed the **Bird of Prey** due to its wing and tail structures that mimic those of an eagle or falcon. Other unique design features include moveable wingtips inspired by feathers, a **next-generation hybrid electric propulsion** system, distributed propulsion and components that would be 3D-printed from state-of-the-art materials. Subscale technology demonstrators could incorporate elements of this concept, but the main goal was to inspire the next generation of aeronautical engineers to help create sustainable and greener aircraft.

In the space realm, NASA made several awards in May with the objective of achieving a human lunar landing by 2024. Maxar Technologies of Colorado received a contract from NASA to design the **Power and Propulsion Element** of NASA's lunar Gateway. The PPE will be a solar electric propulsion spacecraft that will also serve as a communication relay for the **Gateway**.

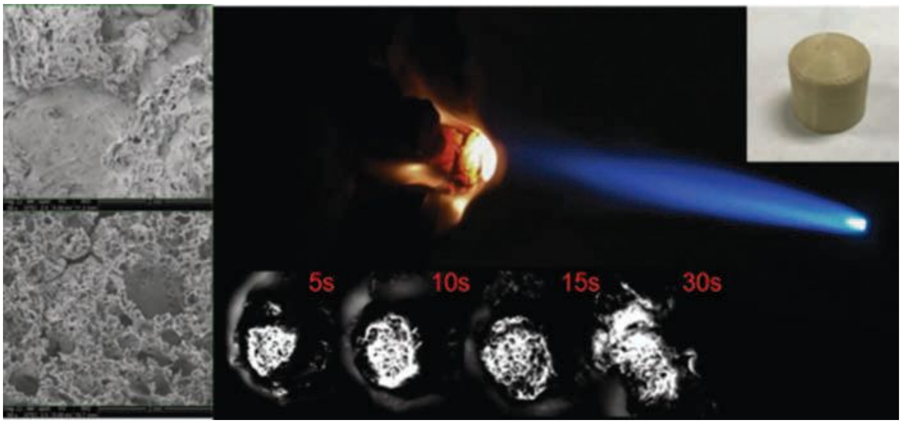
Also, 11 companies in eight states were awarded contracts under NASA's **Next Space Technologies for Exploration Partnerships**. The awardees will conduct studies or produce prototypes of potential human landing spacecraft, with a focus on descent, transfer and refueling. The transfer portion will carry astronauts from the Gateway to low-lunar orbit. The descent portion will transport them from low-lunar orbit to the surface. Refueling capabilities are required for the elements of the landing system to be reusable.

▶ **SpaceX's DEMO-1 Crew Dragon** autonomously docked with the International Space Station in a first for a U.S. commercial spacecraft. The spacecraft is shown in the hangar at Launch Complex 39A in Florida.
SpaceX

NASA conducted ground testing on **five full-size prototypes of deep-space habitation modules**. The testing began in March and lasted several months. The prototypes were made by Bigelow Aerospace of Nevada, Boeing, Lockheed Martin, Northrop Grumman, and Sierra Nevada Corp. of Colorado between 2016 and 2018. During the ground testing, NASA evaluated human factors such as how astronauts would live and work in the Gateway and the ergonomics and capabilities of each habitat. A major objective of the prototype testing was to produce a refined set of design requirements for deep-space habitation modules.

In March, a **SpaceX Crew Dragon** docked autonomously with the International Space Station in a demonstration mission, called **DEMO-1**, without a crew aboard. The docking was the **first by an American commercial spacecraft at ISS** and the first space launch under NASA's **Commercial Crew Program**. Crew Dragon leverages the flight heritage of Dragon, which completed 16 cargo missions to and from ISS prior to the DEMO-1 mission. Crew Dragon consists of a pressurized capsule with environmental control and life support equipment capable of carrying up to seven passengers and an unpressurized trunk for cargo.

In the small satellite launcher market, Virgin Orbit of California in July conducted the first drop test of its **LauncherOne rocket**, a milestone toward its first orbital launch. In the test, an inert LauncherOne was dropped from the Cosmic Girl carrier aircraft, a modified Boeing 747, over the test range at Edwards Air Force Base in California's Mojave Desert. For a space launch, Cosmic Girl will carry a LauncherOne rocket to an altitude above 30,000 feet and release it to boost small satellites to orbit. ★



Unique material innovations reduce costs in manufacturing

BY TERRISA DUENAS AND ED GLAESSGEN

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.

▲ **A sample of 3D-printed** ultraperformance thermoplastic polymer (upper right) was heated by an oxyacetylene torch (center) and photographed over the course of 30 seconds. The post-test pyrolysis zone (top) and charred surface (bottom) are shown on the left side.
KAI LLC

This year the Massachusetts Institute of Technology and Metis Design Corp. collaborated to demonstrate an **"out-of-oven" composite curing process** that addresses the limitations of conventional oven- and autoclave-based processes. Those drawbacks include poor energy efficiency, high operational cost, long cure times and geometrical constraints on the components to be cured. In August, the team demonstrated **carbon nanotube heaters** for conductively curing composite structures without an oven, achieving equivalent thermophysical and mechanical performance to conventionally cured composites, while reducing cure time by 60% and energy consumption by two orders of magnitude. The team believes that this process contributes to the design and manufacturing of next-generation multifunctional architectures by leveraging nanoengineered laminate capabilities such as sensing, **structural health monitoring** and ice protection systems.

In July, KAI LLC, the University of Texas at Austin, RMIT University of Melbourne, Australia, Arkema Inc. and Western Washington University collaborated on a study to utilize **high-temperature fused filament fabrication** technologies to manufacture five unique ultraperformance polymers: SABIC PEI ULTEM 9085, Roboze PEEK, Smart materials 3D PEEK, Arkema Kepstan 7002 PEKK and a modified PEI (ULTEM 1010) material. These can be used in low-heat-flux spacecraft application. The goal of the research was to develop a class of materials and additive manufacturing processes that could one day substantially reduce the manufacturing and assembly costs of **space vehicle thermal protection** systems. All five ultraperformance thermoplastics were able to withstand aerothermal testing at a heat flux of 100 watts per square centimeter for as long as 30 seconds without disintegrating. Based on thermogravimetric analysis **char yield results**, Kepstan 7002 PEKK has the highest char yield of 64% and ULTEM 9085 has the lowest char yield of 43%. High char yield usually indicates material has good ablation performance. In addition to experimental study, computational fluid dynamics analyzed the heat transfer between the specimens under various scenarios compared with material response obtained experimentally.

In February, Nanoarmor LLC and the U.S. Naval Research Laboratory manufactured 70% dense **zirconium carbide composites** using additive manufacturing. These ultra-high-temperature ceramics, or UHTC, offer superior properties that enable their use in leading edges and engine components in extremely high-temperature platforms. Existing refractory ceramics do not offer adequate mechanical and thermal properties to handle extreme environments. Furthermore, corresponding manufacturing methods cannot yield customizable and cost-effective leading-edge components for high-performance aerospace systems. The **Nanoarmor-Naval Research Lab** technique produced inexpensive UHTC zirconium carbide ceramic matrix composites with nanostructured reinforcements that maximize density, hardness and durability under high temperatures and mechanical stress. The polymer-based reaction bonding synthesis route yields **net shape carbides, nitrides and borides** from compressed powder mixtures of metal precursors and carbon-rich resins with high char yields. In addition, the approach is pressureless and incorporates a one-step reactive melt infiltration process that converts preceramic mixtures into dense custom forms at 1,400 degrees Celsius. The approach is significantly **less expensive** than existing alternatives. They reinforced the ceramic matrix composites with metals, fibers, nanocarbons and secondary ceramic phases in order to improve their mechanical strength, thermal conductivity, and resistance to oxidation and ablation. Blends of these precursor materials with polymer binders into suspensions with controllable viscosities unlock capabilities for inexpensive rapid prototyping of customized shapes with tunable dimensions, geometries and properties. ★

Contributors: *Boris Dyatkin, Joseph H. Koo and Brian L. Wardle*

Developers unveil new optimization tools and system designs

BY DOUGLAS ALLAIRE, JOHN HWANG AND 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.

The year saw important advancements at the intersections of multidisciplinary design optimization and **machine learning**.

In January, the University of Central Florida released an open-source implementation of physics-informed neural networks. The work extends recurrent neural networks to cumulative damage models and empowers users to merge physics-informed and data-driven layers within one deep neural network.

In March, the University of Michigan MDO Lab made available its suite of tools for aerodynamic shape optimization, **MACH-Aero**, with two different computational fluid dynamics solvers, **ADflow and OpenFOAM**. The University of Michigan MDO Lab also created **Webfoil**, an application with airfoil data, analysis and optimization.

In June, the University of California, San Diego, Multiscale Multiphysics Design Optimization Lab released an open-source implementation of **efficient large-scale 3D topology optimization** for coupled heat transfer and mechanical stress as well as coupled fluid structure interaction. This paves the way to design highly efficient heat-dissipating and load-carrying lightweight aerospace structures.

NASA's **OpenMDAO**, an open-source high-performance computing platform for systems analysis and multidisciplinary optimization, **V2.8**, was released in June. Later in the year, OpenMDAO V2.8 was used to solve a set of **first-of-their-kind design optimizations** of a boundary layer ingestion propulsor for NASA's **STARC-ABL configuration, short for Single-aisle Turboelectric Aircraft with an Aft Boundary-Layer propulsor**. Throughout the year, OpenMDAO was used as a platform to build several new analysis tools and libraries with analytic derivatives. **OpenAeroStruct** and **OpenConcept** are aircraft design tools developed by the MDO Lab at the University of Michigan; **pyCycle** is a propulsion modeling library developed by NASA's Glenn Research Center in Cleveland; **Dymos** and **Ozone** are two ordinary differential equation integration and optimal-control libraries. Dymos was developed by Glenn and Ozone was developed by the Large-Scale Design Optimization Lab at the University of California, San Diego.

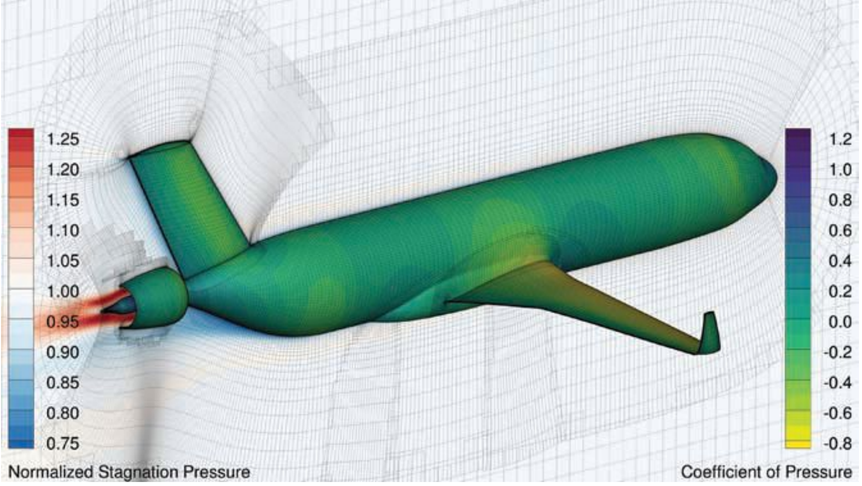
The year also saw important advances in **system design**. In April, there was the **first flight of an unmanned vehicle testbed** designed and built by a team from the Massachusetts Institute of Technology, University of Texas at Austin, Texas A&M University and Boeing's Aurora Flight Sciences. The vehicle is being used to demonstrate the use of reduced modeling and machine learning methods for dynamic data-driven mission replanning. The reduced models also form the basis for a **digital twin** of the vehicle, which MIT is developing with Akselos.

In August, Virginia Tech in collaboration with DK Schmidt and Associates developed approaches to embed dynamics and control of aircraft with highly flexible wings into design environments used to perform multidisciplinary analysis and design optimization of transport aircraft. Researchers demonstrated that **bioinspired internal structural layout** using curvilinear spars and ribs could reduce the structural weight for composite flying-wing aircraft.

Also in August, in collaboration with ISAE-SUPAERO and MIT, NASA's Goddard Space Flight Center in Maryland completed the structural analysis module of a **multidisciplinary design optimization framework**. This framework was applied to the analysis of the James Webb Space Telescope where it was demonstrated that a multifidelity approach can drastically reduce analysis cycles for global sensitivity analyses.

In June, the Multifidelity Modeling in Support of Design and Uncertainty Quantification workshop brought together 40 researchers and practitioners to discuss multifidelity modeling challenges and opportunities and to highlight the progress of multifidelity methods combining physics-based models and machine learning for design optimization and uncertainty quantification. ★

▼ **The ADflow computational** fluid dynamics solver enables the aeropropulsive analysis and design optimization of the NASA STARC-ABL aircraft configuration. Two color maps are shown: pressure coefficient at the surface and normalized stagnation pressure at the symmetry plane.
University of Michigan MDO Lab



Airmen lower an engine from a C-5M Super Galaxy cargo jet for maintenance at Dover Air Force Base, Del. More efficient tools developed by the non-deterministic approaches community are maximizing the service life and safety of jet engines.
U.S. Air Force

Researchers advance probabilistic analysis for greater efficiency and safety

BY ANDREW OLLIKAINEN

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

Next-generation aerospace systems aim for greater efficiency and safety. However, the ever-growing complexity of aerospace systems brings increased test costs. Alternatives to traditional, hardware-focused testing are crucial to the cost-effectiveness of developing new technologies for flight. This presents significant challenges due to the presence of uncertainties and increasingly expensive-to-evaluate simulation models.

In January, the AIAA Certification by Analysis Community of Practice chartered an international team of representatives from industry, academia and governmental agencies to establish **formal guidelines for applying virtual flight modeling** to reduce the burden of flight-testing. Among the areas of focus are model verification and validation methods and uncertainty quantification analysis.

Multifidelity methods that enhance information with cheaper lower-fidelity information sources are key to making design optimization under uncertainty computationally feasible. In January, researchers from the multifidelity, multi-information source, multiphysics, or M3, team led by the Massachusetts Institute of Technology under the U.S. Air Force Multidisciplinary University Research Initiative introduced active learning methods through **multifidelity Efficient Global Reliability Analysis**. In July, M3 introduced a novel **Monte Carlo variance reduction method** via the Information Reuse for Importance Sampling in reliability-based design optimization. These new methods enable computationally efficient implementations of robust optimization to ensure safe, efficient designs.

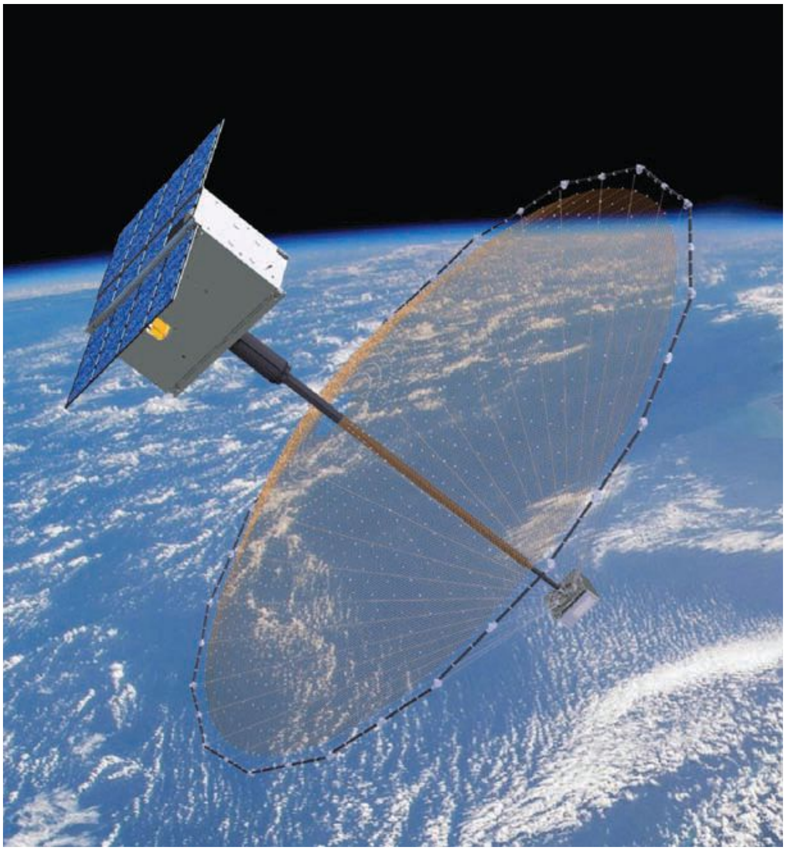
Fleet managers and regulators rely on probabilistic risk analysis to make sure their systems continue to maintain safety throughout their service life. Broader application of these models relies on efficient modeling of material failure. In July, researchers from the University of Illinois at Urbana-Champaign and École Nationale Supérieur de Mécanique et d'Aerotechnique, Poitiers, France, began an analytic study of **structural material deterministic and stochastic failure criteria**. Their work focuses on reducing the dimensionality of material failure analysis under complex loading.

Following the in-service **failure of a commercial jet engine** in 2018, the non-deterministic approaches community has been engaged in supporting all sectors of the aviation enterprise as it addresses the unique challenges of **engine sustainment**. In May, Southwest Research Institute of Texas released a software package to support the **probabilistic damage tolerance methodology** required by the upcoming FAA Advisory Circular AC33.70-5 for FAA certification risk assessment of axial blade slots in aircraft engine disks containing random manufacturing-induced anomalies. The methodology was implemented in the DARWIN probabilistic damage tolerance software (developed by SwRI). The software was created under the guidance of an industry steering committee composed of major international aircraft gas turbine engine manufacturers. Released to the steering committee for review in May, the software will be available to licensed users in early 2020. In July, as part of a joint contract with the U.S. Air Force Research Laboratory and the Probabilistic Analysis Consortium for Engines, SwRI completed a multiyear project to develop new probabilistic methods and tools for assessing uncertainty in **turbine engine component life prediction** in the presence of limited data. ★

Deployable structures expand the capabilities of small satellites

BY MARK SILVER

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



▲ **Artist's rendering of** L3Harris' 5-meter-diameter High Compaction Ratio antenna. The design scales from a 1-meter-diameter dish that fits into a cubesat volume to the 5-meter-diameter dish shown here, which in stowed form takes up one-tenth of a cubic meter, a fraction of a small-satellite volume.
L3Harris

As the role of small satellites in commercial, research and government missions continues to grow, deployable structures are further expanding their capabilities. New small satellite capabilities that deployable structures have enabled include high-gain antennas, accelerated deorbit and solar sail propulsion.

The year began with L3Harris Technologies of Florida introducing a new generation of high-accuracy, large-aperture small satellite antennas called the High Compaction Ratio, or HCR, reflector antenna. HCR ranges from a 1-meter reflector and feed that fits in a 20-by-10-by-10-centimeter volume suitable for cubesat applications, to a 5-m reflector that packages in less than a quarter of an Evolved Expendable Launch Vehicle Secondary Payload Adapter class satellite. The **HCR reflector antenna** is designed for high-frequency, high-gain performance of up to 40 gigahertz. It enables a fast production turnaround to support small satellite constellation development.

L3Harris Technologies also announced that it has begun constructing its 100th **deployable mesh reflector antenna**. This 12-meter-diameter folded rib reflector will be used in a European mission to measure biomass and carbon in forests around the world and is scheduled to launch in 2022. While this milestone is an important one for L3Harris, it is also an important milestone for the deployable structures community because it demonstrates how, with continuous development over the past 50 years, deployable spacecraft structures have become much more widely accepted by the greater satellite industry.

Elsewhere in the industry, in March DARPA launched MMA Design's 2.25 m-diameter **Pantograph Deployed High Gain Reflectarray**, or P-DaHGR, on the Radio Frequency Risk Reduction Deployment Demonstration satellite. P-DaHGR, developed and built at MMA's Colorado facility, offers high-performance, scalable RF capabilities, from UHF to Ka-band, that are specifically designed for small-satellite missions. The reflect array technology can provide equivalent to performance to more complex, parabolic-shaped dishes for missions that do not require large bandwidths.

The use of **high-strain composite deployable mechanisms**, which have thin composite materials that can be rolled or folded, continued to accelerate over the past year. In June, Roccor's HSC drag sail known as ROCFall was launched on the General Atomics Orbital Test Bed satellite. ROCFall, developed and built at Roccor's Colorado facility, will be used to deorbit the satellite at the conclusion of its operations in order to meet the 25-year low Earth orbit lifetime guidelines.

Also in June, the crowd-funded **LightSail-2** spacecraft from the Planetary Society was launched from NASA's Kennedy Space Center in Florida. LightSail-2 is a 32-square-meter solar sail that uses the energy of incident solar photons to provide a propulsive force. While solar sail propulsion was first demonstrated in 2010 by the Japan Aerospace Exploration Agency's IKAROS interplanetary mission, LightSail-2 is the first demonstration of solar sail propulsion in low Earth orbit.

In August, assembly of NASA's **James Webb Space Telescope** was completed at Northrop Grumman's California factory. The final assembly step involved joining the Spacecraft Element and Optical Telescope Element/Integrated Science Instrument Module or OTIS. Once additional tests are completed and Webb unfolds in space following its 2021 launch, it will be the largest space telescope and the first deployable space telescope. ★

Contributors: *Phil Henderson and TJ Rose*

Flapping flight breakthrough and other advances

BY NATHAN FALKIEWICZ AND D. TODD GRIFFITH

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

The year saw major developments in the structural dynamics discipline across industry, national labs and academia.

In the field of airplane design, **AlbatrossOne**, a remote-controlled aircraft made by Airbus in collaboration with United Kingdom universities including Bristol, flew for the first time in February. AlabtrossOne is a scale demonstrator with unique in-flight, flapping wingtips that could revolutionize wing design. The engineers developed what they call a **"semiaeroelastic hinge" concept** to reduce drag and overall wing weight, while combating the effects of turbulence and wind gusts. The team plans to conduct further testing including allowing the wingtips to be unlocked during flight, before the demonstrator, based on the manufacturer's A321 plane, is scaled up further.

▼ **This Orion European Service Module test** article was used to demonstrate application of Quasi-Static Modal Analysis to a complex, large-scale aerospace structure.
NASA

Turning to launch vehicles, in April the NASA Engineering Safety Center examined the applicability of **QSMA, short for Quasi-Static Modal Analysis**, for modeling nonlinear structural dynamic behavior. As an alternative to direct integration of the nonlinear equations of motion, QSMA determines the dependence of frequency and damping on response amplitude using loading behavior from nonlinear static analyses. QSMA was exercised on a nonlinear model of test hardware developed for NASA's **Orion Multi-Purpose Crew Vehicle program**. Excellent agreement was observed between the reduced and full-order nonlinear models, encouraging future employment of QSMA to support accurate and efficient model reduction of structures with bolted joint nonlinearities.

In August, the University of Texas at Dallas, in collaboration with the University of Virginia, National Renewable Energy Laboratory, University of Colorado at Boulder, Colorado School of Mines and University of Illinois at Urbana-Champaign, completed installation of a one-fifth-scale demonstration rotor for a **new offshore wind turbine concept** at NREL's National Wind Technology Center. The full-scale design is a two-bladed, coned, downwind rotor concept with 105-meter blades and rated power of 13.2 megawatts. A key feature of the UT-Dallas structural design is that the subscale 21-m blades are designed having scaled stiffness, structural dynamics and loads (including gravitational, centrifugal and thrust) properties of the full-scale design matched at subscale. This broad set of scaling requirements, which is in addition to strict structural safety design requirements, made this demonstrator design novel and challenging. The team is focused on initial field testing to validate the structural, aerodynamic and aeroelastic performance characteristics of the new concept rotor along with new control strategies for loads reduction.

In the area of unmanned aerial systems, researchers from the University of Kentucky who are in the VibroAcoustics Consortium made measurements close to the surface of a hovering UAS and developed a process for **predicting sound pressure levels at any distance from the UAS**. In addition, U.K. researchers performed pass-by noise tests on UAS that may eventually serve as a basis for standardized measurements. Results were demonstrated to be repeatable to within 1 decibel. UAS noise has been identified as resulting primarily from the blade pass frequency and harmonics. Mitigation approaches for noise reduction of the primary source may take several forms including blade design, operational optimization and structural design. ★

Structures tested; modeling developed

BY HARRY H. HILTON

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

Boeing

▲ **Boeing in January** released an illustration of its latest design for the Transonic Truss-Braced Wing aircraft it is collaborating on with NASA.

In July, NASA demonstrated that the Orion spacecraft launch abort system can jettison astronauts to safety during launch emergencies. The test was another milestone for the Artemis program, which is dedicated to sending Americans back to the moon and eventually to Mars. During the test, a representative Orion crew module was launched from Cape Canaveral on a modified Peacekeeper missile built by Northrop Grumman. The test version Orion experienced maximum expected high-stress aerodynamic loadings, traveled to a 6-mile (9.7-kilometer) altitude and reached Mach 1.3 when the planned abort sequence triggered.

In June, NASA began structural testing of the largest component for the United States' new deep space rocket, the **Space Launch System**, at NASA's Marshall Space Flight Center in Alabama. The liquid hydrogen tank, which is 64.6 meters tall and has a diameter of 8.4 m, comprises two-thirds of the rocket's core stage, and it holds, at minus 217 degrees Celsius, the approximately 2 million liters of supercooled liquid hydrogen necessary to power the RS-25 engines. During those tests, which wrapped up in September, dozens of hydraulic cylinders in a **66-meter-tall test stand** pushed and pulled the tank, subjecting the test article to the same stresses endured during liftoff and flight.

The **Mechanics of Structure Genome project** at Purdue University continued its ongoing multiscale modeling effort that seeks to provide a new, unified approach to modeling composite anisotropic heterogenous structures. MSG simplifies multiscale composite modeling by determining and executing only necessary analyses to sufficiently capture the relevant physics. MSG also provides a rigorous yet efficient approach to handling complex buildup structures. The Purdue team developed a companion code, **SwiftComp**, as constitutive modeling software for virtual structures and materials testing, as well as for executing finite element analysis codes for efficient, high-fidelity composite material modeling. This year, the MSG project developed an **MSG-based multiscale Timoshenko model**, an efficient and accurate multiscale method for predicting failure envelopes that uses MSG-based thermo-viscoelastic multiscale modeling and AI-assisted, MSG-based multiscale modeling.

Arizona State University continued developing a computationally efficient multiscale modeling framework for nanoengineered composites. With support from the Office of Naval Research, investigators studied **material behavior across multiple length scales** while quantifying analysis uncertainty. These efforts in nanotechnology led to the fabrication and application of carbon nanotube-enhanced carbon fiber reinforced polymer composites and nanoengineered novel architectures (such as radially grown fuzzy fiber composites). This approach was used to characterize elevated-temperature mechanical properties of thermosets reinforced with randomly dispersed carbon nanotubes.

GKN Fokker and Gulfstream continued to assess **thermoplastic composites as primary aircraft structures**. High out-of-plane strength and sustainability/recyclability are some of the thermoplastic advantages. Efforts to develop cost-effective manufacturing technologies continue across the globe — particularly in the Netherlands.

Boeing continued to refine the design of the **proposed hypersonic, passenger-carrying airliner** it unveiled at the 2018 AIAA Aviation Forum in Atlanta. It is similar to an uncrewed hypersonic surveillance and reconnaissance concept the company presented in January; both have a general delta-wing configuration with dual rear fins, streamlined fuselage and sharp nose. The vehicle could travel at up to Mach 5 and cross the Atlantic and Pacific oceans in two and three hours, respectively, Boeing said.

Boeing made public its newest **Transonic Truss-Braced Wing design** in January at the AIAA SciTech Forum in San Diego. Researchers say this aircraft would fly higher and faster than the previous TTBW concepts. Originally, the TTBW was designed to fly at Mach 0.70 to Mach 0.75; engineers modified the design for more aerodynamic efficiency while flying at Mach 0.80. By adjusting the wing sweep angle, the resulting optimized truss can more efficiently carry lift, thus allowing designers to increase the wingspan to 51.8 m with a folding wing concept. The integrated design is expected to increase the aircraft's cruise speed. ★

Contributors: *Siddhant Datta, Zhenning Hu, Bruce D. Willis, Michael Wolff and Wenbin Yu*

▲ **NASA researchers** swung this Fokker F-28 MK1000 jet into terrain in June to measure the effects on crash test dummies and the structure.
NASA

Reducing laser damage, acquiring aircraft crashworthiness data

BY AMEER G. MIKHAIL, BRIAN J. BARLOW AND JASON A. SAWDY

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

The U.S. Air Force this year continued studying the effects of high-energy lasers on composite aircraft skins and testing mitigation technologies against thermal damage. These tests under the **High Energy Laser program** centered on back surface fire, penetration vulnerability and the screening of potential hardening technologies. Results of this **Joint Aircraft Survivability Program Office** effort will establish a baseline thermal radiant field. Various hardening technologies supplied by the Air Force Research Laboratory, Naval Research Laboratory and Air Force Institute of Technology were applied to structures to determine their ability to mitigate or delay laser damage.

The Air Force conducted tests on five fuel tanks of various sizes to gather data about their **vulnerability to fuel vapor explosion** due to threat-induced tank ullage ignitions. Five tanks of 950- to 5,300-liter capacity were studied, with testing on the fifth tank completed in October. Ullage conditions and fuel temperatures were varied to determine ullage overpressure ratio curves for each of the tanks. Tests were conducted under pressure conditions ranging from ambient to under 28 kilopascal. Five hundred tests were completed, and about 650 expected by the end of the program. The data will aid the defense industry in fuel tank design and structural integrity studies and will be used in the **Next Generation Fire Prediction Model**.

In June, NASA's Langley Research Center conducted a **swing test into terrain** with a Fokker F-28 MK-1000 aircraft at the Landing and Impact Research Facility in Virginia. The aircraft was **released from a height of 31 meters** with significant vertical and horizontal velocities. The primary objective of the test was the generation of full-scale crash data in support of proposed **FAA aircraft crashworthiness guidelines**. Secondary objectives included the evaluation of effects on standard and advanced **crash test dummies** designed for increased biofidelity and with enhanced instrumentation. The effects on these **anthropomorphic test devices, or ATDs,** depended on the seat-to-floor load paths and structural deformation, which was measured by onboard sensors and photogrammetric techniques. Langley researchers developed a 3D model of the crash for purposes of a simulation that will be improved through a validation process. The aircraft contained 24 ATDs, five of which were advanced experimental. The fuselage and dummies contained a total of 500 sensors to capture accelerations and loads. The test was conducted in cooperation with the FAA. Additional partners included the U.S. Army, the National Highway Traffic Safety Administration and the National Transportation Safety Board.

In the military space arena, the U.S. Defense Department in March created the **Space Development Agency** to accelerate the development of next-generation small satellite architectures. These proliferated constellations would be harder to attack than the small number of large satellites that today provide critical services mainly through the Air Force.

NASA's vision for landing humans on Mars by the late 2030s hinges on achieving survivability to two to three years of continuous weightlessness and bombardment by cosmic ionizing rays on the crew and their capsule. Until effective protective solutions such as astronaut suits and protective capsule can be developed, astronauts will make use of the **planned lunar Gateway** as a staging station for the eventual human mission to Mars. In May, NASA awarded a contract to Maxar Technologies of Colorado for the **Gateway's Power and Propulsion Element** and in July to Northrop Grumman for the **habitation module**. In preparation, NASA plans to launch an uncrewed Orion module on a heavy-lift Space Launch System rocket in late 2020, followed by the **first launch with a crew** in 2022. ★

Contributor: *Martin S. Annett*

Progress made on U.S. acquisition policy and technical fronts

BY JEFFREY NEWCAMP

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

Systems engineering leapt ahead in 2019 with the enactment of a United States Code change, large advances in modular open systems architecture research capabilities for digital twin technology and a new U.S. Air Force strategy.

In January, Azad Madni, Carla Madni and Scott Lucero published a comprehensive call to action for applying **model-based systems engineering, or MBSE**, to digital twin technology. MBSE gives systems engineers another tool with which to develop solutions for complex problems in the digital twin realm. The authors project that digital twins will continue to transcend the obvious applications for aircraft and complex machines and grow in fields like construction and real estate. This landmark publication inspired systems thinkers and reflected the momentum that the topic gained this year.

In May, researchers led by Madni at the University of Southern California founded the **Distributed Autonomy and Intelligent Systems Laboratory**. According to Madni, executive director for the USC systems architecting and engineering program, "In July, we demonstrated rudimentary digital twin technology for multiquadcopter search missions. [Then] in September, we demonstrated rudimentary digital twin technology for autonomous cars." This groundbreaking research showed the capability to collect data from the autonomous cars to populate the digital twin.

According to Mike Sievers, USC lecturer and senior systems engineer at NASA's Jet Propulsion Lab in California, "The USC lab's work aims to develop an open architecture and tool set that facilitates plug-and-play experimentation for cyber-physical systems." An open architecture for digital twins can expand the market for the technology because creating **digital twin platforms** is expensive and time-consuming. Sievers and his colleagues believe that digital twin progress this year has been instrumental for industry, government and university developers. Open architecture could lead to a watershed moment for system development, as other technologies have recently experienced. Building open architecture systems is analogous to opening the floodgate.

Starting Jan. 1, **10 U.S. Code section 2446a** began requiring any defense acquisition programs reaching Milestone A or Milestone B to design and implement a **modular open systems, or MOSA**, approach. The Defense Department desires highly cohesive, loosely coupled and severable modules in new weapon systems that will increase both flexibility and acquisition competition. A team of researchers at the Air Force Research Laboratory's Munitions Directorate at Eglin Air Force Base, Florida, spent 2019 expanding its take on a MOSA. They built the **Munitions Open Architecture Test and Evaluation Lab, or MOATEL**, where they can test interchangeability of components for kinetic weapons.

MOATEL allows engineers to test adherence to 10 U.S. Code section 2446a and specifically targets module interfaces. For example, MOATEL engineers can test whether a newly acquired missile's seeker can be replaced by a higher tech seeker without negatively impacting system performance. This capability may increase system lethality for the Department of Defense and decrease system lifecycle cost.

▼ **Aircraft manufacturers** can perfect a design before prototyping with digital twins.
Siemens illustration

In April, then-Air Force Secretary Heather Wilson released a **science and technology strategy** for the service. It focuses on systems-of-systems innovation, how the service manages technological projects and provides a call to action for the future. Systems engineering is a principal actor to use for solving technical Air Force problems and will be used extensively during this strategy's implementation.

As 2020 overtakes 2019, the systems engineering discipline will become larger, more relevant and more capable because of the policy and progress achieved in the past year. ★

Increasing power, speed and mobility without the negative impacts of noise

BY NATHAN E. MURRAY

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.

Seeking to understand the interactional noise mechanisms associated with unmanned air systems and urban air mobility vehicles, researchers at NASA's Langley Research Center in Virginia conducted experiments in September in the **Low Speed Aeroacoustic Wind Tunnel**. The research team measured the aerodynamic and acoustic performance of **multiple propellers** interacting with a traversable, meaning moveable, wing geometry.

In March, the U.S. Transportation Department's Volpe Center in Massachusetts, in conjunction with the Helicopter Association International HeliExpo 2019 and the Fly Neighborly Committee, released an online pilot and operator training program through the website of the **FAA WINGS** pilot proficiency program. Aircraft noise data and modeling developed in partnership with NASA, FAA and the U.S. Army was inserted directly into the WINGS training program to help pilots fly quieter.

Co-rotating propellers are tested in proximity to a traversable wing geometry in the Low Speed Aeroacoustic Wind Tunnel at NASA's Langley Research Center to assess acoustic directivity and amplitude sensitivity to parameters including relative phasing of the propellers as well as spatial location of the wing relative to the propeller disks.
NASA

With funding from Uber Elevate, the Advanced Acoustic Model simulation tool, a computer program that calculates community noise from aircraft flight operations, was updated in May by Volpe to support research in the assessment of **community noise** and audibility of electric vertical takeoff and landing aircraft.

In June and July, NASA and FAA conducted **helicopter noise abatement** tests at Coyle Field, New Jersey, with a Sikorsky S-76D, a U.S. Coast Guard HH-65 Dolphin (a variant of the commercial Airbus AS365 Dauphin), a Leonardo AW139 and a Bell 205 with the goal of improving community acceptance of helicopter operations.

In the area of supersonic flight, researchers briefed the **International Civil Aviation Organization's Working Group 1**, which is concerned with aircraft noise, in April about the results of the November 2018 sonic thump community response testing in Galveston, Texas. The results of the flights by NASA F/A-18 jets were also briefed at AIAA's Aviation Forum in June. Data from the **Galveston flights** is helping guide researchers in preparation for community response flights by NASA's X-59 low boom demonstration aircraft.

In July and August, NASA F/A-18 test aircraft flew over the Mojave Desert where researchers from Volpe and Brigham Young University tested a **30-mile-long microphone array** in preparation for acoustic testing and validation of the X-59.

Turning to conventional jets, analyses of measured flyover noise data from a full-scale Boeing 737-7 with a NASA-designed **advanced inlet acoustic treatment** demonstrated a 3.2 decibel cumulative reduction in inlet noise. Research progressed this year toward meeting NASA's Advanced Air Transport Technology goal of 4 db or 37% airframe noise reduction for a **high-lift tube and wing configuration**. This progress was enabled by a December 2018 test in the 14-by-22-foot Subsonic Tunnel at Langley in which a novel in-wall microphone array isolated slat noise from other noise sources. This array was recessed behind an **acoustically transparent screen** to perform measurements on a 10%-scale high-lift aircraft model.

Sponsored by the U.S. Office of Naval Research, researchers from Lockheed Martin, Spiritech and Penn State completed an investigation of the noise reduction potential of Spiritech's STAR, for **Multi-Stream Coupled Throat Variable Rotating**, nozzle concept. The May results showed significant noise reductions for static takeoff engine power settings when compared with contemporary tactical aircraft jet exhaust nozzles.

Also this year, significant facility advancements were made. Specifically, improved microphone array measurements were realized in May when ATA Engineering and the University of California, Irvine, performed jet noise measurements using a collection of both stationary and continuously **moving microphones**. The technique approached the theoretical limits of a continuous series of sensors using only a modest number of microphones.

Advancements in aeroacoustic wind tunnel testing were realized in June when NASA's Glenn Research Center in Cleveland completed a **renovation of the 9-by-15-foot Low Speed Wind Tunnel** using a novel "aerodynamically smooth but acoustically transparent" surface developed in collaboration with Jacobs Engineering and Virginia Tech. The new lining makes the walls of the tunnel seem acoustically invisible and virtually eliminates the problem of separating the noise of the wind tunnel itself from the noise of the flow over the test article mounted inside the tunnel.★

Contributors: *Christopher Bahr, Cliff Brown, David Lockard, Doug Nark, Eric Nesbitt, Juliet Page, Tony Pilon, Parthiv Shah, Jonathan Rathsam and Nik Zawodny*

Enabling diagnostics for opaque flows, complex surfaces and nonintrusive flow measurements

BY THOMAS P. JENKINS AND DAVID H. PLEMMONS

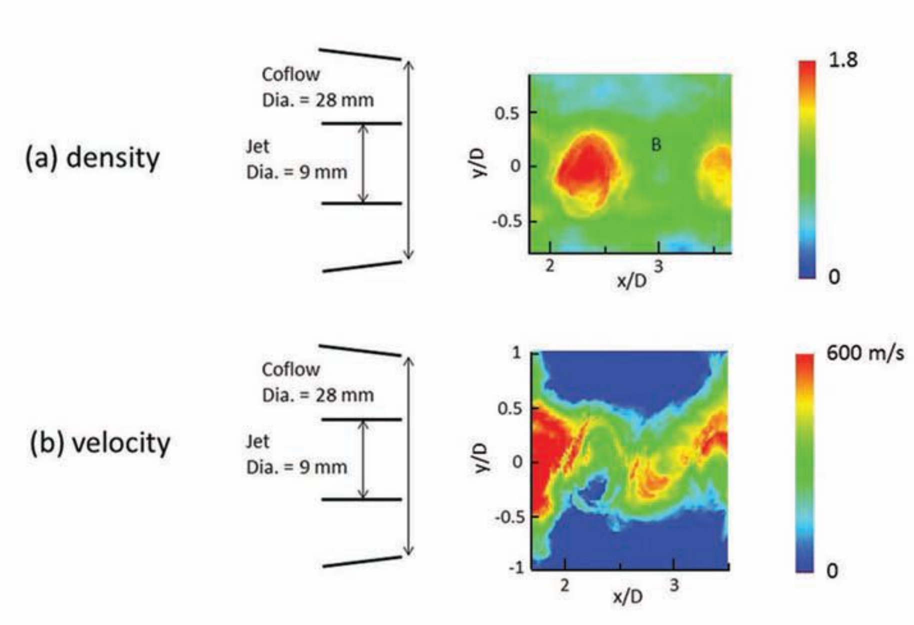
The **Aerodynamic Measurement Technology Technical Committee** advances measurement technology for ground facilities and aircraft in flight.

In January, Huixuan Wu's group at the University of Kansas demonstrated a novel **magnetic particle tracking technology, or MPT**. Unlike other advanced flow diagnostic methods, MPT tracks an object with a magnetic field. It does not rely on optics and can be used in a completely opaque environment. Meanwhile, it does not involve radioactive materials or X-rays, so the operation is safe and easy. Although this idea dates back to at least the 1990s, previous researchers relied on optimization algorithms to reconstruct the particle trajectory. However, optimization is time-consuming, which limits its application. Wu's group replaced the optimization-based approach with the use of a **nonlinear Kalman filter**, which increased the speed of reconstruction by three orders of magnitude and increased the accuracy and resolution. In May, the University of Kansas team applied the MPT technique to investigate a sheared dense granular flow in a Couette cell. They observed many interesting phenomena, such as the tendency of horizontal alignment of rods in the flow.

In April, **DLR, the German Aerospace Center**, applied **temperature-sensitive paint to engine nacelles** to investigate laminar-to-turbulent transition. The combination of **carbon nanotubes and temperature-sensitive paint, or cntTSP**, can measure boundary-layer transition on complex 3D wind tunnel models, since the carbon nanotube layers create homogeneously distributed surface heating. The cntTSP sensor can visualize the surface boundary-layer temperature distribution that arises due to the different heat transfer coefficients for laminar and turbulent flow. A wide area of interest for the use of cntTSP is the integration of the different cntTSP layers into complex 3D geometries like nacelles, which the aircraft industry needs to improve the data quality of wind tunnel tests. In the research, DLR investigated the applicability of cntTSP to a generic nacelle at the cryogenic test facility **Pilot European Transonic Wind Tunnel**. The team achieved flow visualization of the laminar to turbulent boundary-layer transition appearing on the nacelle.

In July, as part of a U.S. Air Force-sponsored project, MetroLaser Inc. demonstrated **a diagnostic method** for spatially resolved simultaneous measurements of density and velocity that can be applied to supersonic flows and that does not require flow seeding. The method, named **two-cell filtered Rayleigh scattering**, involves illuminating the measurement region with a laser sheet and measuring Rayleigh-scattered light from the flow with two cameras, each filtered by an iodine vapor cell of a different pressure. The methodology is based on a mathematical model that relates the Rayleigh-scattered light collected through the filter to the pressure, temperature and velocity of the flow. The model was used to convert the measured light intensities to density and velocity for each point in a 2D image of the flow. MetroLaser demonstrated the technique on a supersonic coflow jet and correctly captured the **2D density field** both spatially and quantitatively. The team also demonstrated feasibility of measuring the 2D velocity field, but limitations in the simplified image registration method used for this feasibility study resulted in some errors in the spatial velocity distribution. The use of more rigorous **image registration methods**, along with suggested improvements in the selection of iodine cell pressures, should enable the method to achieve an estimated 4% accuracy in both density and velocity in an optimized system. ★

Contributors: *Christian Klein and Huixuan Wu*



▼ **Two-dimensional** images of the freestream-normalized density (a) and the velocity (b) of a supersonic coflow jet consisting of a fast-moving core flow and a surrounding slower concentric flow. The coflow jet is used for demonstrating these nonintrusive flow diagnostics.

MetroLaser Inc.

Testing designs to increase aircraft fuel efficiency

BY NATHAN HARIHARAN

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

▲ A NASA-Boeing 4.5% scale of a Transonic Truss-Braced Wing aircraft is tested in the 11-Foot Transonic Tunnel at NASA's Ames Research Center.

Boeing/NASA

A new NASA design method, referred to as **Crossflow Attenuated Natural Laminar Flow**, was model-tested in June in the National Transonic Facility, a high-pressure, cryogenic wind tunnel at NASA's Langley Research Center in Virginia. CATNLF carefully designs the leading-edge shape of the wing to enable natural laminar flow on typical transport wings with high sweep and Reynolds numbers. Laminar flow has been studied for decades because of its promise for reducing fuel burn via decreased aircraft drag. Laminar flow on typical transport wings would provide the largest performance benefit, but previous laminar flow strategies required the vehicle to either fly slower or add a complex suction system, and both penalties made the technology too costly to buy its way onto the aircraft.

Transition visualization techniques used in the June wind tunnel test showed a near doubling of the extent of laminar flow over the extents previously seen in any natural laminar flow experiment on wings with comparable sweep. Encouraging wind tunnel results have spawned a series of flight tests to further advance the CATNLF technology in flight environment.

In January, rotorcraft researchers reported making significant strides in determining the importance of flow transition and understanding mechanisms of **vortex-wake breakdown**. The findings were published at AIAA's Hover Prediction Workshop in San Diego.

Whether a helicopter station keeps above a highway to report the traffic or stays in close proximity to the side of a mountain to deliver supplies to a remote community, hover is an elegant and complicated flight condition. **Numerical simulation of hover** is full of challenges but offers the reward of great understanding of performance and loads. Better understanding will lead to more efficient, capable and safer rotor designs. The upcoming NASA-sponsored tests at the National Full-Scale Aerodynamics Complex at NASA's Ames Research Center in California will offer an even richer data set for code and process benchmarking. These tests are scheduled for mid- to late 2020.

In August, NASA and Boeing, as part of the High Aspect Ratio Wing Subproject within the NASA Advanced Air Transport Technology Project, completed tests on the **4.5%-scale, Mach 0.80 Transonic Truss-Braced Wing**, or TTBW, model in the Ames 11-Foot Transonic Wind Tunnel. The objectives were to acquire a test database to validate the aerodynamic performance and vehicle stability and control characteristics. Force and moment, surface pressure, model deformation, oil flow visualization and drag rise data were collected to support the assessment of stability and control characteristics. Data were obtained at Reynolds numbers ranging from 2 million to 8 million per foot and Mach numbers ranging from 0.2 to 0.92. The TTBW concept shows promising fuel burn benefits toward meeting NASA system level metrics.

In May, **a new active flow control innovation** was tested under NASA's Advanced Air Transport Technology project, using a 10%-scale high-lift version of the Common Research Model with simple-hinged flaps at Langley's 14- by 22-Foot Subsonic Wind Tunnel. The objective of the test was to investigate a novel high-lift method that eliminates Fowler-flap mechanism and external fairing on a conventional high-lift configuration. **High-lift configurations** are needed only during takeoff and landing phases of any flight and are typically retracted during cruise phase of the flight. Eliminating external fairings associated with conventional Fowler-flaps reduces the drag during the cruise phase of the flight and saves fuel. The active flow control innovation, **High Efficiency Low Power actuators**, achieved a targeted lift coefficient increase of 0.50 using a moderate amount of mass flow and air pressure. The simple-hinged flap configuration equipped with this actuation technology was able to match or exceed the lift performance of the reference conventional high-lift configuration. ★

Contributors: *John Lin, Michelle Lind, Latunia Melton and Robert Narducci*

A year of exploration and commercialization of space

BY BRIAN C. GUNTER

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

▲ **A stack of 60 Starlink** satellites ready for launch. SpaceX has approval to launch about 12,000 global broadband satellites.
Starlink

The astrodynamics community was active in a number of exploratory and commercialization efforts this year, starting with NASA's **New Horizons** spacecraft's January flyby of **Ultima Thule**. Following the flyby of Pluto by New Horizons in 2015, the encounter with Ultima Thule, a binary Kuiper Belt object orbiting approximately 6.6 billion kilometers from the sun, represents the **most distant planetary body ever reached by a spacecraft** and returned valuable imagery and other data regarding these remote and ancient objects.

Exploration of the solar system continued with other notable achievements from ongoing deep-space missions, such as the close approaches to the sun by NASA's **Parker Solar Probe** (the third of which was in September) and multiple touchdowns and sample-collection maneuvers by the Japan Aerospace Exploration Agency's **Hyabusa2** mission at the **Ryugu** asteroid.

While not a deep-space mission, the crowd-funded **LightSail 2** mission developed by the California-based Planetary Society deployed its 32-square-meter solar sail in July and later verified that the satellite was able to raise its apogee by the solar radiation pressure on the sail. By demonstrating "flight by light" for cubesats, the mission has paved the way for future small satellites to explore the solar system without the use of traditional propulsion systems.

In June, the U.S. Air Force Research Laboratory launched **its Demonstration and Science Experiments, or DSX**, mission to study the radiation environment of near-Earth space. By July, the mission had unfurled its long antenna booms, including one pair measuring 80 m (262 feet) tip-to-tip, to become the largest uncrewed three-axis stabilized spacecraft ever flown.

In February, **OneWeb** moved closer to its goal of providing global internet services with the launch of its first six satellites. The satellites were raised to their final 1,200 km orbit and demonstrated data rates up to 400 megabytes per second. These satellites represent the first of an initial constellation of **650 satellites** that will ultimately grow to a total of 1,980 satellites. SpaceX reached a similar milestone in May when it launched the first 60 satellites of the Starlink constellation into orbit. **Starlink** seeks to also provide global broadband services with an approved constellation of nearly **12,000 satellites** in orbits ranging in altitude from 340 km to 1,150 km. In July, Amazon's **Kuiper Systems** proposed an additional broadband constellation of **3,236 satellites**, with all satellites targeting an altitude below 630 km. If all three "megaconstellations" reach full implementation, this would represent 17,000 new orbiting satellites, significantly increasing the number of objects in low Earth orbit and highlighting policy concerns regarding regulation of space activity and orbital debris.

The private utilization of space took another step forward when the **Beresheet** mission launched in February and attempted to land on the **lunar surface**. Israeli-based nonprofit **SpaceIL** developed the mission, and although the lander ultimately crashed during the final descent phase, it represented the first attempt by a private entity to land a payload on the moon. Another lunar milestone was achieved a few weeks earlier when **China's Chang'e-4** was the first to place a lander and rover on the far side of the moon in January. A separate effort by the Indian Space Research Organization to place the **Vikram lander** on the lunar surface was attempted in July, nearly coinciding with the 50th anniversary of the **Apollo** lunar landing. Communications were lost with the lander during the descent; however, the primary lunar orbiter, **Chandarayaan-2**, was fully operational as of November and was to proceed with its seven-year mission to study the composition of the lunar surface. These international attempts to return to the moon, complemented by NASA's Artemis lunar exploration program, show the global renewed interest in lunar research and exploration. ★

The XQ-58A Valkyrie demonstrator completed its inaugural flight in March at Yuma Proving Ground, Arizona.
U.S. Air Force

Paving the way for autonomous weapons, hypersonics, human spaceflight

BY CHRISTOPHER D. KARLGAARD

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

In March, the U.S. Air Force's **XQ-58A Valkyrie** unmanned combat aerial vehicle took off from Yuma Proving Ground in Arizona on its first flight. San Diego-based Kratos Defense and Security Solutions designed and built the XQ-58A under contract with the Air Force Research Laboratory as a low-cost strike aircraft demonstration vehicle. The contract was awarded in July 2016. The Valkyrie design incorporates stealth technology that can carry weapons or surveillance payloads. Four more flight tests are planned in order to further evaluate the vehicle's performance.

AFRL's **X-60A hypersonic research vehicle** program completed its critical design review early in 2019. The X-60A is an air-dropped, single-stage, suborbital vehicle powered by a liquid-fueled rocket motor. It was designed as a research platform for conducting flight tests of hypersonics technology in the range of Mach 5-8 at altitudes between 70,000 to 130,000 feet (20-40 kilometers). The X-60A is designed to be dropped from a NASA C-20A aircraft. AFRL is conducting the project in partnership with Atlanta-based Generation Orbit Launch Services Inc. With the critical design review complete, vehicle fabrication was underway with the plan of the first test flight from Cecil Spaceport in Jacksonville, Florida, in early 2020.

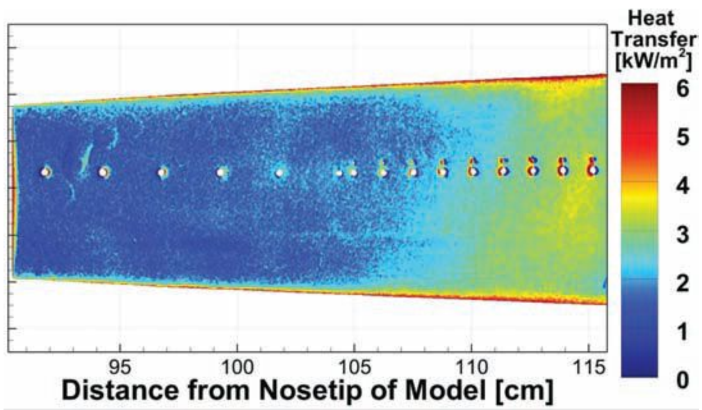
The **SpaceX Crew Dragon Demo-1** launched on a SpaceX Falcon 9 from Kennedy Space Center on Feb. 28 before docking with the International Space Station on March 3. The uncrewed orbital flight test carried cargo and a simulated passenger. It then undocked on March 8, reentered the atmosphere and splashed down in the Atlantic Ocean. The success of this test was a milestone in the SpaceX Crew Dragon program, paving the way for a flight test with crew for the Demo-2 mission. In April, the Crew Dragon capsule that flew for the Demo-1 flight test was destroyed during a ground test of the SuperDraco engines, the abort engines that would carry the Crew Dragon away from a failing Falcon during launch.

NASA's Orion program tested its **Launch Abort System, or LAS**, in July. The Ascent Abort-2 flight test was launched on a modified Peacekeeper first-stage missile from Kennedy Space Center in Florida. The booster carried the capsule and LAS to an altitude of approximately 30,000 feet at Mach 1.15. The LAS then initiated the abort flight test, pulling the Orion capsule test article away from the booster and reorienting the vehicle for **splashdown** into the Atlantic Ocean. Data acquired during the July test will be used to validate preflight models and to prepare for the Artemis-1 mission in which a Space Launch System rocket will boost an uncrewed Orion capsule around the moon. ★

Experimental-numerical campaigns give insight into complex fluid phenomena

BY DAVID GONZÁLEZ AND ALBERT MEDINA

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.



▲ **First-ever measurements of hypersonic** boundary-layer transition on a straight cone under fully quiet flow conditions. Heating to the wind tunnel model surface starting at 108 cm is caused by the flow near the surface transitioning from smooth, laminar flow to chaotic, turbulent flow.

Purdue University

Advances in the field of fluid mechanics serve as testament to the breadth and rigor of the discipline, with contributions spanning all regimes from low-speed to hypersonics. In a first, researchers at Purdue University observed a **hypersonic boundary-layer transition** on a 2.5-degree half-angle straight cone under fully quiet flow conditions. These experiments in February at the **Boeing/Air Force Office of Scientific Research Mach-6 Quiet Tunnel** documented the growth, breakdown and transition to turbulence of the second-mode instability. This mechanism dominates laminar-turbulent boundary layer transition in hypersonic flows and is characterized by a trapped acoustic wave. Researchers observed the primary manifestation of the increase of heat transfer near transition onset and its continual subsequent increase until the end of the cone.

Shock-wave boundary-layer interactions are ubiquitous in high-speed flows, existing on internal and external surfaces of a supersonic/hypersonic flight vehicle. These interactions result in flow separation, vortical structure formation, pressure losses, induced pitching moments and other effects that are often detrimental to the vehicle's operation. Researchers at Florida A&M University, Florida State University and the U.S. Air Force Research Laboratory collaborated in April and May in a study involving high-fidelity experiments and numerical simulations for the Air Force Office of Scientific Research to understand the flow physics associated with shock-wave boundary-layer interactions and shock-shock interactions on an axisymmetric configuration. The researchers performed **flow visualizations and pressure measurements** at Mach 2. Results showed that a shock emanating from the wedge impinges on and wraps around the body leading to crossflow separation and reattachment, features that greatly differ from the well-documented 2D/3D canonical shock-wave boundary-layer interactions configurations on flat surfaces.

Integrated approaches employing complementary experimental and numerical campaigns such as that described above continue to provide fundamental insight. These are critical to developing a deeper understanding of high-speed fluid dynamic phenomena and enable the formulation of highly accurate modeling and advancement of simulation capabilities. Such complex-modeling proficiencies will facilitate the development of **materials suitable for the austere environments**, the development of potential flow control techniques to mitigate heat transfer in key areas of interest and the efficient design of next-generation high-speed flight vehicles.

Regarding low-speed aerodynamics, researchers at AFRL pioneered the use of **large-eddy simulation** to study the flow processes leading to the onset of stall for a rapidly pitching airfoil. This effort, completed in March, highlighted the importance of understanding the unsteady boundary layer development as the pitching airfoil approaches the dynamic stall event. The researchers applied large-eddy simulation over a range of Reynolds and Mach numbers as well as to finite wings, including sweep effects and standard wind tunnel end-plate conditions. The technique resolved a highly complex flow field in which a transitioning, separated, nonequilibrium boundary layer interacts with a locally supersonic flow. The research resulted in an innovative flow control concept and insight into the unsteady interactions responsible for the dynamic stall event.

Between September 2018 and May 2019, researchers at Los Alamos National Laboratory in New Mexico developed **physics-constrained machine learning algorithms** for spatio-temporal modeling of turbulence, owing to a paucity of machine learning algorithms capable of effectively modeling 3D datasets. Specifically, they developed neural networks with a combination of convolutional and recurrent architectures that account for spatial and temporal nonlinearities in fluids. The resulting model can replicate **high-fidelity 3D turbulence** at a computational cost several orders of magnitude lower than traditional numerical schemes. The performance of these learning algorithms was quantified on well-known cases in turbulence with strong physics-based metrics. ★

Contributors: *Stuart Benton, Brandon Chynoweth, Rajan Kumar, Arvind Mohan and Steven Schneider*

Facility improvements make progress amid heavy year of ground testing

BY PAT GOULDING II

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

The ground test community saw significant facility investments and improvements in 2019, building on efforts begun in previous years, and produced an impressive array of critical test data.

NASA began final verification in September on its largest investment in aeronautics research in several years — the acoustic improvements to the **9-by-15-foot Wind Tunnel** facility at NASA's Glenn Research Center in Cleveland. Final commissioning was expected to occur in December. It will cap nearly two years of work to retrofit existing portions of the wind tunnel circuit and replace the flow liner material in the test section in order to **reduce background noise** by up to 9.3 decibels. This dramatic improvement in noise attenuation will permit more accurate test and evaluation of **newer and quieter turbofan propulsion systems**, ensuring the facility remains viable and retains its status as a premier acoustics research asset for propulsion systems for decades to come. Customer testing was scheduled to resume in December, following the final commissioning.

Meanwhile, a team from the U.S. Air Force's Arnold Engineering Development Complex continued to make progress toward restoring full test capabilities at the **National Full-Scale Aerodynamics Complex** at Moffett Field, California, while also executing several test programs in the facility's **40-by-80-foot Wind Tunnel** in 2019. The complex suffered a Class A mishap in June 2017 that destroyed all blades on one of its six fan motors. The team continued efforts throughout 2019 to repair and retrofit the **80-by-120-foot Wind Tunnel** — the largest wind tunnel in the world — with the intent of restoring the test capability by early 2020. Efforts are also ongoing to **design, procure and install a complete new set of fan blades** on all six drive motors. This will restore the facility test capability to levels from before the 2017 mishap and drastically extend the service life of the drive system.

Facility improvement projects proceeded internationally as well. Throughout 2019, **JAXA, the Japan Aerospace Exploration Agency**, continued to improve the performance of its **new bird-strike test apparatus** at Chofu and to work toward formal commissioning in 2020. The structure was installed in March 2018 and uses precisely calibrated gelatin balls of specified density to simulate bird strikes. It boasts a test speed range of 50 to 400 meters per second (112-895 mph). JAXA also spearheaded efforts to **advance wind tunnel wall interference correction capabilities** by expanding existing 3D wall panel method codes to incorporate the unique boundary characteristics of Kevlar wall tunnels. Initial results showed excellent agreement, and the method stands to provide significant insight to future test customers across a broad array of facilities.

Back in the United States, NASA saw significant test achievements, particularly in programs at NASA's Langley Research Center in Virginia and NASA's Ames Research Center in California. Teams at Langley completed extensive testing related to **NASA's Space Launch System**. This testing, completed in June, included deployment of a **novel laser-based flow visualization technique** in the Langley Unitary Plan Wind Tunnel as well as low-speed lift-off and transition testing in the 14-by-22-foot Wind Tunnel. NASA also ran several tests at Langley, Glenn and Ames from March to September that involved iterations of NASA's **Common Research Model**, studying high lift, laminar flow and acoustic characteristics. ★

Contributor: *David Stark*

The newly modified test section in the 9-by-15-foot Wind Tunnel at NASA's Glenn Research Center has an improved acoustic liner to minimize tunnel background noise and improve acoustic measurement quality.
NASA

AI advances military drone effectiveness, lunar exploration

BY UDAY J. SHANKAR AND KEVIN P. BOLLINO

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

The Dragonfly rotorcraft will sample materials and determine surface composition in different geologic settings on Saturn's Titan moon.
Johns Hopkins Applied Physics Laboratory

Intelligent automatic control relies heavily on **artificial intelligence and machine learning**. The U.S. Department of Defense is making major progress in research and development in the field of autonomy amid a renewed emphasis on robotics and autonomous systems.

In March, William Roper, assistant secretary of the U.S. Air Force for acquisition, technology and logistics, announced **Skyborg**, the Air Force's future AI-enabled fleet for unmanned combat aerial vehicles. Skyborg will augment crewed fighter jets with **autonomous drones** as their "wingmen." This ongoing pursuit of fully autonomous aircraft that leverage AI and machine learning focuses not only on the combat systems but also on the infrastructure and development environment such as networks and cloud servers to improve overall aircraft effectiveness.

In another AI-related initiative, the Air Force is developing the **Air Force Cognitive Engine software** application, which was in beta testing in April, as its core infrastructure for AI development to stimulate technological advancements in aircraft, spacecraft and missiles.

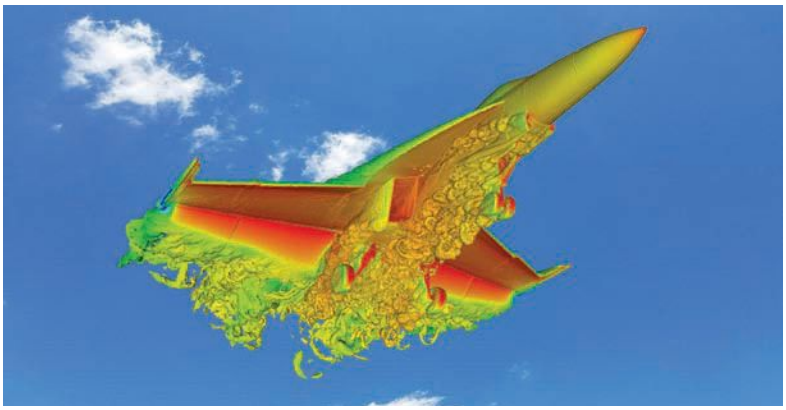
For its next **New Frontiers** mission, NASA selected the **Dragonfly rotorcraft** in June to explore the icy, unique and richly organic world of **Titan**, Saturn's moon. From a guidance, navigation and control perspective, two items stand out: the use of a rotorcraft and autonomous navigation. Dragonfly has an approximate 10-times advantage in power-to-weight ratio on Titan as compared to Earth. Dragonfly will have **inertial and terrain-relative navigation** with an inertial measurement unit and optical sensors, enabling navigation and hazard detection in a feature-poor terrain with soft and diffused lighting. This maturation of drones follows the development of miniature sensors, autopilots and hazard-detection methods. Dragonfly will be launched in 2026 and arrive on Titan in 2034.

In the 50th anniversary year of **Apollo 11**, three missions sought to land on the moon, with a fourth planned for launch. In January, **China's Chang'e-4** became the **first spacecraft to land on the far side of the moon**. The lander released a rover, Yutu-2, which is exploring the basin of the Van Karman crater. The **Queqiao relay satellite** — the first satellite in a halo orbit at the Earth-moon L2 Lagrangian point — relays communications between ground stations and the spacecraft. In contrast to the success of Chang'e-4, the **Israeli Beresheet** and the **Indian Vikram landers crashed** during final descent to the moon. In April, during Beresheet's critical landing phase, it appears its inertial measurement unit reset, shutting down the main engines. In September, the Vikram lander appeared to have a nominal descent until its fine breaking phase, when communication was lost. The Indian Space Research Organization is still looking for answers. Meanwhile, the co-manifested **Chandrayaan-2 orbiter**, which reached its lunar orbit in August, is functioning well. Finally, in December, China was scheduled to launch the Chang'e-5 lander and sample return — the first since Luna-24 in 1976. ★

Achieving advanced CFD capabilities with high-performance computers

BY JAMES MASTERS AND CAROLYN WOEBER

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 CFD grid with 2.4** million surface triangles and 202 million volume cells was generated on a U.S. Navy F/A-18E Super Hornet with the landing gear extended using NASA's TetrUSS grid-generation software. The image depicts iso-surfaces of vorticity colored by pressure and clearly shows that the wake from the landing gear and doors extends far downstream.
U.S. Navy

As problem size and complexity increases, the meshing community continues to grapple with effective utilization of **high-performance computing platforms**, which was one of the impediments laid out in NASA's Computational Fluid Dynamics Vision 2030 study. In January, representatives from Pointwise, Symmetric, Cascade Technologies and Cambridge Flow Solutions made strides toward this goal by demonstrating the ability to generate and **process meshes up to 13 billion elements**. Exascale computing on extremely large data sets was further addressed in June when compression algorithms developed at **Oak Ridge National Laboratories** in Tennessee demonstrated the ability to **compress time-accurate, unsteady, CFD data from 4.7 terabytes to 568 gigabytes**. And Tecplot's subzone load-on-demand data structure allowed transient solutions of 10 billion elements to be saved and stored on an engineering workstation.

New Jersey-based Intelligent Light, funded by a U.S. Department of Energy Phase II Small Business Innovation Research grant, developed an uncertainty quantification proof-of-concept for large datasets called **Spectre-UQ**, which demonstrated in January a technique to arrive at the total uncertainty for a numerical study.

Computational environments enabling **rapid multidisciplinary design** are becoming increasingly important. In response to this trend, the **Computational Aircraft Prototype Syntheses research program**, of which the Massachusetts Institute of Technology and Syracuse University are primary developers, provided infrastructure to enable **multifidelity, multidisciplinary, physics-based aircraft design**. In June, the **Aerospace Analysis and Design in Virtual and Augmented Reality toolKit, or AArDVARK**, an engineering-oriented virtual and augmented-reality framework leveraging the CAPS infrastructure, demonstrated several relevant applications, ranging from packaging to modal analysis. These demonstrations highlighted how the appropriate utilization of **virtual reality** can augment traditional engineering analysis techniques.

Also on the computational environments front, the Computational Research and Engineering Acquisition Tools and Environments program released **version 10.0 of Kestrel** in May and **version 10.1** in August. Support for axisymmetric 2D flow solutions was added to the primary finite volume flow solver in version 10.0 and to the high-order finite element solver in version 10.1. This allowed for 3D bodies of revolution to be simulated in 2D while still reporting loads consistent with the full 3D configuration. With the newest versions, it is also possible to restart a simulation with a different mesh system and visualization error from the Mach Hessian.

High-order meshing algorithms continued to make significant progress. In June, researchers at Mississippi State University demonstrated an advancing-layer method for **generating curved boundary layer meshes**. Pointwise entered its second year of a NASA Phase II SBIR to develop a high-order mesh capability that involves mixed-order degree elevation and adaptation. High-order mesh generation up to degree three is also now available in Capstone, as well as the corresponding high-order visualization. MIT, Pointwise and Intelligent Light also continued to explore **high-order visualization**. Intelligent Light won a Phase II SBIR in June to pursue visualization for high-order simulations.

In January, **Capstone** released version 10, which includes hexahedral elements in the boundary layer and tangential adaptivity for boundary layers, allowing users to generate automatic smooth transitions with the unstructured mesh. Version 10 also enhanced geometry capability with new repair techniques.

Pointwise completed an SBIR Phase I contract for the U.S. Air Force in March that focused on access to computational geometry from within the flow solver. **MeshLink**, an open source library released in May as part of the contract, solves the problem of **geometry-mesh associativity** while providing simplified access to the supporting geometry during mesh manipulation and adaptation.

Finally, researchers from the **French National Research Institute** made a significant advancement in **turbomachinery applications** when they demonstrated the viability and efficiency of unstructured anisotropic mesh adaptation techniques to turbomachinery applications including internal regions with periodic boundaries. ★

Training pilots to handle the worst with realistic simulators

BY DANIEL KEATING

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 March, all pilots from scheduled air carriers in the United States began using **flight simulators** to meet federally mandated upset prevention and recovery training requirements. The FAA ordered the simulator training before the two **Boeing 737 MAX** crashes that have been attributed to loss of control. Meeting these requirements should improve the airline safety record, as the rare occurrences of loss-of-control in flight still represent the leading cause of fatalities in the worldwide commercial jet fleet. From 2016 to 2019, the FAA approved 400 simulators for training after improvements in the machines' **aerodynamic modeling**. To date, the overwhelming feedback from airline pilots who have taken the training has been positive.

Turning to **urban air mobility**, which NASA defines as a safe and efficient system for air passenger and cargo transportation within an urban area, passenger acceptance is one of the many challenges to it becoming a reality. To help address this challenge, NASA's Ames Research Center in California this year prepared a new simulator cabin called **Ride Qualities Cab** to run with the center's Vertical Motion Simulator, following an August design review. A **four-passenger cockpit with a wrap-around visual system** was mated to the center's vertical motion simulator. The Vertical Motion Simulator's large amplitude motion system enables researchers to explore ride quality in a safe and cost-effective manner.

Also, **eye-tracking technologies** are rapidly advancing and finding applications in flight simulation and training. Several companies are providing eye-tracking systems to measure pilots' focus in response to various stimuli. A study was conducted in August with a **level-D full flight simulator** — the highest standard, which includes motion feedback — at a U.S.-based airline. Eye tracking was used to determine the effects of having the flight director (the roll and pitch attitude guidance on the primary flight display) on or off on pilots' ability to monitor the flight path effectively. This study was part of a joint FAA/Ames project toward improving pilot training for flight path monitoring. Further research is required to identify the usefulness of eye tracking in training.

Virtual reality technologies from the gaming industry are beginning to make their way into various aspects of flight simulation, and training applications in particular. Airline applications include **cabin crew training, maintenance training** and special-purpose pilot training, such as head-up display familiarization where the optics are focused at infinity. At NASA, the use of VR for astronaut training will increase with new training requirements being introduced for long-duration space missions. In addition, the Air Force is looking to increase the use of VR to bridge the training-to-experience gap. An experiment was performed at Ames in September to investigate how performing a roll control task in VR compares to performing the task in a simulator with conventional visuals, and if pilots' utilization of peripheral visual cues is different. Another experiment focused on determining the visual-motion thresholds for VR sickness, which is still the biggest factor preventing the technology from reaching its full potential for training. ★

***Contributors:** Steven Beard, Jeffery Schroeder and Peter Zaal*

▼ **View from inside the** cockpit of the Ride Qualities Cab simulator cabin.
NASA

Promising technologies from plasmas, lasers, directed energy

BY SALLY BANE AND JOSEPH W. ZIMMERMAN

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

▲ **The Tactical High-Power** Operational Responder was developed to defend air bases against swarms of drones.
Air Force Research Laboratory

This year was prolific for advanced studies and demonstrations of plasma and directed energy technologies in aerospace.

In a leading development, the U.S. Air Force Research Laboratory demonstrated the **Tactical High-Power Operational Responder, or THOR**, anti-drone technology in June. THOR applies a high-powered microwave beam to **disrupt drone electronics**, causing the drone to crash. Researchers envision this transportable system as a means to counter major military threats, including **disabling swarms of drones** within its beam path simultaneously.

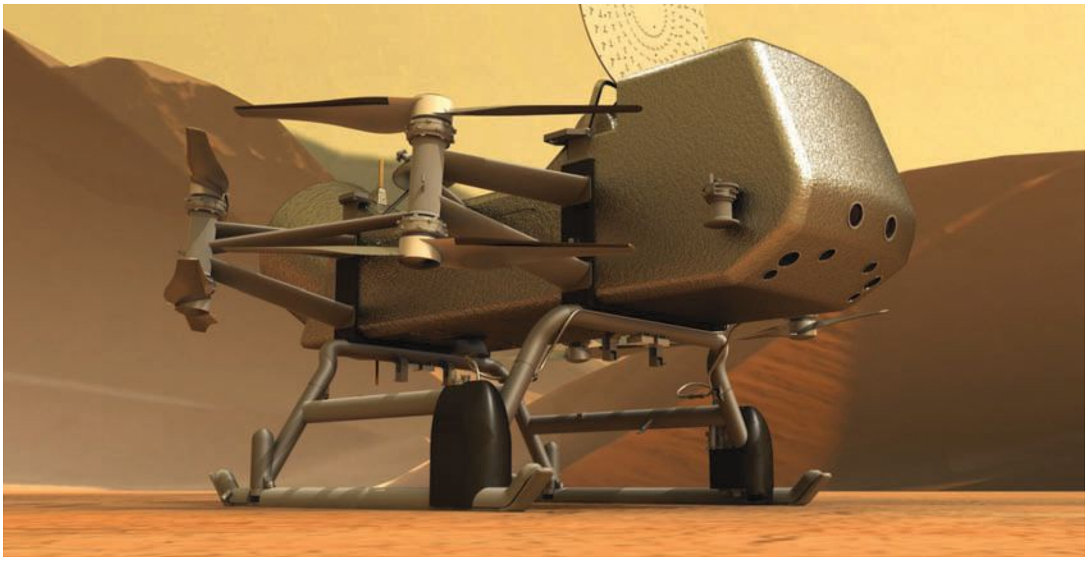
In January, Emory University researchers reported advancements in **optically pumped rare gas metastable lasers**, in which they doubled the optical pumps applied to a resonator volume containing an argon gas discharge to achieve an output power of 7 watts. Scaling of a similar xenon-based laser was also demonstrated with 1 W output. This **new laser technology**, which operates at near infrared wavelengths, is a potential logistically simplified alternative to the classic high-power diode-pumped alkali lasers.

In July, researchers at Princeton University published about new work that pushed the boundaries of the diagnostic method **Electric Field-Induced Second Harmonic Generation**, which applies a femtosecond laser beam to enable **time-evolved electric field measurements** in partially ionized plasmas. This technique is extremely valuable as the electric field is a critically important parameter for tailoring plasmas for a wide range of applications, from plasma flow and combustion control to plasma medicine. The researchers achieved measurements of electric fields with subnanosecond time resolution and spatial resolution down to tens of microns, allowing clear measurements of an ionization wave propagating with a velocity of 0.3 millimeters per nanosecond.

In June, plasma-assisted combustion researchers from the Aerospace Department at Texas A&M University presented on simulations predicting a decrease of the **deflagration-to-detonation transition time** in ducts obtained using localized plasma perturbations. The plasmas were modeled as sources of radicals introduced in front of a deflagration flame propagating in a stoichiometric hydrogen/air mixture with turbulent flow. These preliminary results demonstrate the potential of plasmas for decreasing deflagration-to-detonation transition time and **increasing turbulent burning velocity**.

Researchers at **Xi'an Jiaotong University** in China reported on efforts with new plasma approaches for both plasma-assisted combustion and plasma flow control. In February, they presented a new plasma-assisted combustion approach that uses the heating and reforming effects of gliding arc discharges in a swirl-stabilized burner to **extend the lean ignition and extinction limits**. In August, this same group presented research that applied a **"stream-wise plasma heat knife"** installed on the leading edge of an airfoil model to perform anti-icing and de-icing. The novel technology applies an array of streamwise-oriented nanosecond-pulsed dielectric barrier discharges to provide rapid-response local heating to the airfoil leading edge.

Notre Dame researchers working with Innovation Technology Applications Co. continued to report encouraging results from **drag-reduction experiments** using arrays of pulsed-direct-current dielectric barrier discharge plasma actuators. The plasma actuators produced a spanwise velocity component in the boundary layer, resulting in **as high as 76% viscous drag reduction** over a surface in the Mach number range of 0.05 to 0.5. The most recent experiments, reported on in September, demonstrated this technology embedded in a NACA 63-012A airfoil model with free stream Mach numbers in the range of 0.3 to 0.5, providing 45% reduction in viscous drag as a well as a net power savings that increased with Mach number. ★



Dragonfly will have eight rotors to fly to locations on Titan to search for prebiotic chemicals.

Johns Hopkins Applied Physics Laboratory

Advances in thermal management for hypersonic flight and Titan exploration

BY AARON BRANDIS, JONATHAN BURT AND CHARLES BERSBACH

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

Dragonfly, a mission to send a robotic octocopter lander to Saturn's largest moon, was selected in June for **NASA's New Frontiers 4 program**. The Johns Hopkins Applied Physics Laboratory leads the **Dragonfly mission**, whose goal is to study prebiotic chemistry and habitability of the ocean world that is **Titan**. Due to the dense, calm atmosphere and low gravity on Titan, an octocopter is an ideal vehicle to explore a variety of locations. Thick insulation and heat from the **Multi-Mission Radioisotope Thermoelectric Generator, or MMRTG**, maintain the lander interior at relatively benign temperatures, typical for space components throughout the mission. The MMRTG is particularly effective on Titan as it emits heat along with charging the batteries that provide the power required for flight. Dragonfly requires sustained heat for thermal management because it can't rely on solar power on Titan. The moon's distance from the sun and hazy atmosphere combine for a surface temperature of minus 179 degrees Celsius.

Working with scientists led by NASA's Ames Research Center in California, Dragonfly's team is also proposing an instrumentation suite to obtain aerothermal data relevant to **thermal protection system, or TPS**, design during the atmospheric entry phase. The entry instrumentation package aims to measure near-surface and in-depth TPS temperatures, surface pressure, total heat flux and radiative heat flux.

Multiple advancements were made this year in the area of high-speed flight. In January, DARPA began an initiative called the **Materials Architectures and Characterization for Hypersonics, or MACH**, program. MACH seeks to develop new materials and designs for cooling the hot leading edges of hypersonic vehicles flying more than five times the speed of sound, Mach 5. The first goal is to develop fully integrated leading-edge solutions for use in near-term hypersonic vehicles. In May, researchers at Sandia National Laboratories finished high-speed experiments that for the first time **characterized the vibrational effect of the pressure field** beneath a turbulent hypersonic region. The pressure field is key to understanding how intermittent turbulent spots affect vehicles flying at Mach 5 or higher, and these advancements in understanding may lead to better vehicle design.

In March, Reaction Engines Limited, or REL, completed the **first phase of high-temperature ground testing** for its pre-cooler heat exchanger. To rapidly cool air entering a gas turbine engine under supersonic or hypersonic flight conditions, the pre-cooler pumps gaseous helium through several thousand microtubes. Tests were conducted at an REL test facility in Colorado, where the pre-cooler was subjected to the exhaust stream from a General Electric J79 turbojet engine. The **pre-cooler** was able to quench 420-degree Celsius intake air to around 100 degrees in less than 0.05 second, for a heat transfer rate of approximately 1.5 megawatts at inflow conditions corresponding to a freestream Mach number of 3.3. The pre-cooler is intended as a component of the REL Sabre hybrid air-breathing rocket engine and for other hypersonic flight applications including vehicle thermal management and extending the operable Mach number range of gas turbine engines. ★

Developing parachute systems for space and military

BY OLEG YAKIMENKO

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.

Parachutes for the SpaceX Crew Dragon and the Boeing CST-100 Starliner spacecraft were tested throughout 2019, aimed at completion of qualification and reliability tests to fly humans in early 2020. Both companies have said they plan on starting human flight in 2020.

NASA declared the results of November's Starliner's pad abort test to be acceptable, even though one of the capsule's three main parachutes did not deploy due to a loose pin.

The parachutes that will ensure NASA's **Orion spacecraft** floats safely back to Earth passed a milestone in September with completion of the system acceptance review for the Orion **Capsule Parachute Assembly System**, or CPAS. The last major piece of paperwork certifying CPAS is scheduled to be signed in March 2020 after Lockheed Martin completes parachute mortar testing. Throughout 2019, the CPAS team at NASA's Johnson Space Center in Houston also worked on installation of the flight hardware into **Artemis-1** (formally known as Exploration Mission-1 or EM-1), which is the uncrewed lunar orbital test flight of the Orion capsule, expected to be launched in late 2021.

CCDC SC, short for U.S. Army Combat Capabilities Development Command Soldier Center, was focused during the year on developing technologies to improve **cargo and personnel airdrop capabilities.** CCDC SC conducted tests in March and June on self-guided cargo systems, including novel control methods and sensors to increase accuracy in environments without GPS. Follow-up tests were scheduled for October and December. Throughout March and July, CCDC SC conducted modeling of flow behavior around various cargo aircraft to test the interaction with both cargo payloads and human jumpers. Work on added **safety for troop parachutes** included the development of an automatic activation device for the T-11 reserve parachute employed during static line mass assault operations and a smart snap hook that notifies aircrew in the rare event of a towed parachutist.

In May, CCDC SC began developing key components of the **Heavy Equipment Large Low Velocity Airdrop System** for 27,000- to 36,000-kilogram payloads. It also ground-tested the ATAX modular airdrop platform — which uses airbags — culminating in two crane drops in preparation for live airdrop testing.

▲ **A 19,000-kilogram test** of a cluster of eight G-16 parachutes.
U.S. Army

The U.S. Army Product Manager Force Sustainment Systems, or PM FSS, completed testing in August of the **G-16 cargo parachute**, which will replace the G-11 cargo parachute that was introduced 60 years ago. The G-16 can be deployed at lower altitudes because it has a new method for controlling the canopy's opening. The G-16's construction can cut the cost over the life of the parachute because of its modularity and simplified repair procedures. Zodiac Parachute and Protection America, now called Safran Parachute & Protection America, developed the parachute with Fox Parachute Services under contract to the Army.

In April, PM FSS also completed testing of the **Extracted High- and Low-Speed Container Delivery System**, or EHLSCDS, which includes the G-15 cargo parachute, 2.8-meter-diameter high-speed extraction parachute and A-24 cargo container. EHLSCDS can deliver up to eight extracted CDS payloads at altitudes as low as 160 meters with indicated airspeeds of up to 426 kph and is compatible with both C-17 Globemaster III and C-130J Super Hercules cargo aircraft. Airdrops with high-speed extraction at low altitude reduces both exposure on the drop zone and threat to aircraft. The G-15 will be a partial replacement for the legacy G-12 until future payload certification work will allow for the G-12's full replacement. ★

Contributors: *Ricardo Machin, Kristen Ryan and John Watkins*

Adapting air traffic control for drones and urban air mobility

BY DAVID THIPPHAVONG

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

Global airline industry profits are projected to dip from $30 billion in 2018 to **$28 billion in 2019** because of a projected 14.3% increase in fuel costs and a 5.3% increase in labor costs, according to the **International Air Transport Association**. The return on invested capital of 7.4% is projected to be only 0.1 percentage points above the cost of capital. In North America, a net post-tax profit of $15 billion is expected in 2018, with a net post-tax profit margin of 5.5%. The relatively strong economic performance in North America is attributed to the consolidation of commercial airlines, which has helped maintain high passenger and cargo loads, and increased ancillary revenues that have blunted the impact of **higher fuel costs**.

NASA, the FAA, the National Air Traffic Controllers Association and industry have been developing concepts and technologies to improve the **handling of arrival, departure and airport surface traffic**. In July, NASA expanded operational testing for its integrated arrival, departure and surface, or **IADS, program** to the North Texas area. NASA's Airspace Technology Demonstration 2 project developed IADS to save fuel and emissions, reduce congestion on taxiways, and improve compliance with controlled takeoff times for managing overhead stream insertion. IADS has been tested at Charlotte Douglas International Airport in North Carolina since September 2017 and, in two years, saved airlines 1.4 million kilograms (3.1 million pounds) of fuel and **reduced carbon dioxide emissions** equivalent to planting 71,031 urban trees.

Government agencies opened doors to development of new types of aircraft and operations. The FAA took steps toward establishing standards for the return of **civil supersonic flight** in the U.S. In June, it proposed streamlining the process for obtaining approval to flight test supersonic aircraft. The FAA expects to publish a **proposed rule for noise certification of supersonic aircraft** by March 2020. Besides noise, supersonic operations will also need to demonstrate safe integration into the National Airspace System with existing and other emergent air traffic operations.

Beyond airline operations, NASA and its partners made progress toward building a framework for **safe, routine operation of small unmanned aircraft systems in the airspace**. In June, NASA, the FAA, the Nevada Institute of Autonomous Systems and 18 industry partners completed Technical Capability Level 4 flight tests in Reno, Nevada. It consisted of **five sUAS** completing 150 missions in downtown Reno and a nearby park. This testing was the first of its kind with multiple sUAS simultaneously flying beyond visual-line-of-sight operations in an urban environment. In August, Technical Capability Level 4 testing continued in Corpus Christi, Texas, to gather operational data in a hot and humid urban environment and over open waters.

The **UAS Technical Capability Level 4 flight tests** have also become important to development of UAM, short for urban air mobility, which industry, academia and government are increasingly pursuing. In October, NASA said recent work had focused on extending the UTM tests for sUAS to UAM operations. Also in October, NASA released details of how industry could apply to test and demonstrate technology in partnership with the agency through a series of **UAM Grand Challenge activities**, with the first event expected to occur in mid- to late 2020. In these activities, NASA provides the proving ground to facilitate the UAM community in testing and demonstrating their technologies and other capabilities that address foundational UAM safety and integration barriers. The UAM community will need to work together with the broader aviation community to demonstrate that UAM vehicles can be operated safely with regard to other vehicles in the air and people and property on the ground. ★

▼ NASA researchers work with software in the agency's air traffic management laboratory as part of Airspace Technology Demonstration 2.
NASA

Busy year for advancing emergent flight vehicle technology

BY MICHAEL J. LOGAN AND MICHAEL L. DRAKE

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

▲ **Stratolaunch is the** world's largest airplane by wingspan, stretching 117 meters across and extending 73 meters from nose to tail with a maximum gross takeoff weight of 590,000 kilograms.
Stratolaunch

Developer Franky Zapata flew a **jet-powered hoverboard** across the English Channel in August, crossing roughly where Louis Bleirot made the first flight across the channel 110 years previously. In April, pilots evaluated Stratolaunch, a twin-fuselage, six-engine, satellite launcher with a 117-meter wingspan, during a nearly 2½-hour flight from Mojave, California, the aircraft's first.

This year also saw steady development of major commercial and military programs and intense activity around electric (or hybrid electric) propulsion, autonomous and **electric vertical takeoff and landing, or eVTOL**, aircraft (many of which are aimed at the urban air mobility market).

Governments continued to nurture potential new aircraft technologies. In July, the European Aviation Safety Agency released its final Special Condition for VTOL aircraft. The rules apply guidance for distributed propulsion vehicles with **lift/thrust powerplants**, applicable to vehicles with up to nine passengers and a 7,000-pound (3,100 kilograms) gross weight. NASA awarded funds for subsonic-transport electric propulsion studies for potential electrified aircraft propulsion, hoping to lay the groundwork for a future flight demonstrator. Its electric-powered **X-57 Maxwell** began ground runs of its Mod II in June, testing the electric motors and propellers in an initial spin test. In August, the United Kingdom's prime minister announced the **Future Flight Challenge**, funding development of technologies for **electric-powered passenger aircraft**, cargo drones and urban air taxis.

There were also a few notable first flights among electric and small autonomy vehicles. In January, Boeing's Aurora Flight Sciences subsidiary completed first flight of its **autonomous passenger air vehicle**, an eVTOL configuration, at its Virginia facility. Germany-based **Lilium Jet's five-seat prototype**, with tilting ducted fans, flew in May. H55's battery-powered Bristell Energic, a **more conventional configuration** manufactured by BRM Aero in the Czech Republic, made its first flight in June from Sion, Switzerland. The aircraft has an endurance of 1.5 hours, targeting roughly an hour of pilot training flight time. Also in June, a modified Cessna 337, the Ampaire 337, first flew — its rear engine replaced with an electric motor, powered by lithium-ion batteries. The objective is a configuration with a piston engine optimized for cruise, using the electric motor to supplement for takeoff and climb. The California-based startup Elroy Air flew its Chaparral, an **autonomous cargo VTOL drone**, in August.

In commercial transport aviation, Airbus launched its A321XLR, the longest-range variant of its A321neo family, targeting to achieve ranges up to 4,700 nautical miles. In April, Embraer obtained regulatory approval from Brazilian, European and U.S. regulatory agencies for its E-195-E2. The latest variant of the E195 demonstrated over 25% lower fuel burn than its predecessor. Also in April, the Polish-built **Flaris LAR 1**, a single-engine personal jet, made its first flight. Mitsubishi announced launch of its U.S. scope clause compatible SpaceJet M100 in June. The 76-passenger aircraft will be tailored to work within the operational capacity and weight limitations of many U.S. operators. Two new business jets were certified during the year. Gulfstream achieved FAA Type Certification in June for its **G600**. In September, Cessna announced its FAA Type Certification of the **Cessna Longitude**.

On the military side, new developments included flight of the **Kratos XQ-58A Valkyrie**, an unmanned combat aerial vehicle, in March. The demonstrator was developed under the U.S. Air Force Research Laboratory's Low-Cost Attritable Aircraft Technology initiative. In March, the Sikorsky-Boeing **SB-1 Defiant** first flew. The compound helicopter, with rigid coaxial rotors, is targeting the U.S. Army's Future Vertical Lift program objective of vertical lift with substantially higher cruise speed and ranges than conventional helicopters. Shortly after the Defiant's first flight, in April, the An-24 replacement Ilyushin Il-112V light military transport made its first flight. In September, Boeing's **MQ-25**, an autonomous aerial refueler for the U.S. Navy, flew for the first time. ★

Aviation automation in spotlight; new-entrant evolution continues

BY TOM REYNOLDS

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

The role of aircraft automation systems and their certification were major issues in aviation operations this year after the high-profile crashes of **Boeing 737 MAX** aircraft in October 2018 and March 2019. In both cases, behavior of the Maneuvering Characteristics Augmentation System, or **MCAS**, was implicated, and the aircraft type was grounded worldwide in March. MCAS is designed to enhance pitch stability so that the MAX behaves more consistently with other B-737 variants. **Redesign and recertification of the system** were underway as of November. Despite the crashes, as of mid-October, the **international aircraft fatality rate was 20% below** the five-year average reported by the Aviation Safety Network.

The industry also continued planning for **trajectory-based operations**, which leverage time-based management, information exchange between air/ground systems and the aircraft's ability to fly precise paths in time and space. The FAA has recognized that operations in challenging weather conditions will play a key role in achieving maximum benefits. In August, NASA started transitioning automation technology known as the **Dynamic Routes for Arrivals in Weather**, or DRAW, to the FAA to assist in this regard. DRAW integrates advanced models of pilots' behavior around convective weather cells to predict the future aircraft trajectory and maintain trajectory-based operations that are currently discontinued in these conditions.

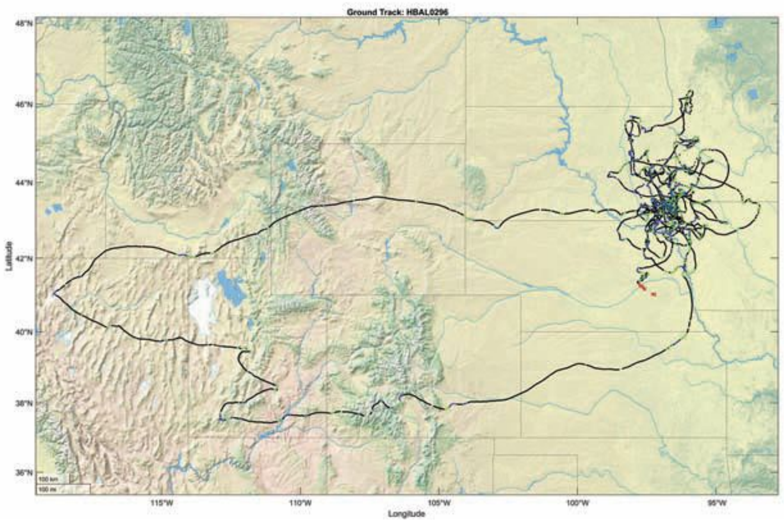
▼ **The first commercial** launch by a SpaceX Falcon Heavy in April carried the Arabsat-6A satellite.
SpaceX

This year also saw significant progress in unmanned aerial systems operations. A number of operators or companies have received **special authorization** through the FAA's public-private partnership **UAS Integration Pilot Program** to fly drones over people or beyond visual line of sight. In April, Alphabet's Wing Aviation was the first drone operator awarded an air carrier certification. In March, UPS and Matternet made **the first U.S. revenue-generating drone delivery** of medical samples. NASA completed its technical demonstrations of increasingly complex **UAS Traffic Management** operations involving small UAS with **Technical Capability Level 4** tests in Reno, Nevada, in May, and Corpus Christi, Texas, in August. These demonstrations tested operation of UAS in high-traffic urban applications and included beyond visual-line-of-sight and contingency-management operations.

Companies also continued development of urban air mobility, or UAM, vehicles and traffic management concepts. In August, Volocopter became the **first company to fly** an electric-vertical-takeoff-and-landing aircraft at an international airport (Helsinki) while integrated into the air traffic management system. NASA and Uber are continuing their collaboration, and in October a joint simulation activity used their respective automated traffic management technologies to land simulated vehicles at the same virtual vertiport. In October, NASA kicked off its **UAM Grand Challenge** project, a public-private partnership focused on a series of increasingly complex demonstrations of UAM vehicles and operations. On-demand helicopter services were introduced in select locations in the U.S. In July, Uber started **Uber Copter** services between New York City's John F. Kennedy International Airport and downtown Manhattan, while Airbus' Voom started services **across the San Francisco Bay Area** in September. They join Blade, which has operated in multiple cities across the U.S. since 2014.

In terms of commercial space, 2019 saw the **first revenue-generating launches** of the SpaceX Falcon Heavy. Meanwhile, Blue Origin, Virgin Galactic and other commercial space companies edged closer to regular operations. In August, Virgin Galactic declared its base at Spaceport America in New Mexico ready for commercial operations, which it plans to start in 2020. The FAA is developing decision support systems to help facilitate safe, efficient and equitable access to airspace as space and other new entrants evolve. ★

Contributors: *Tamsyn Edwards, Gabriele Enea, Antony Evans and John Koelling*



◀ **Raven Aerostar's Flight 296** balloon flew within 160 kilometers of Sioux Falls, South Dakota, for 20 days of its 40-day mission.

Raven Aerostar

Demonstrating navigation, persistence; carrying out spacecraft tests

BY 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.

Raven Aerostar balloons logged 7,500 flight days in the stratosphere as part of scientific, military and commercial missions, with an average flight duration of over 140 days. In June and August, a **Thunderhead 208 balloon** demonstrated persistence in a designated area by keeping within 100 miles (160 kilometers) of Sioux Falls, South Dakota, for 28 days. After the balloon exited the area, Raven Aerostar brought it back with wind steering and again put it into persistent mode to stay in the area around Sioux Falls.

In June, the company demonstrated **waypoint navigation** with three balloons it launched from Maryland, flew across the country and brought down in a predesignated landing area in Northern California. After traveling 2,100 nautical miles, the balloons landed within 80 km of each other. In another demonstration of waypoint navigation and persistence, Raven Aerostar launched three balloons from the California coast in July and directed them over the Pacific Ocean for specific missions. One was directed to fly back to the Raven Flight Operations Center in Sioux Falls; another was sent to Hawaii, where it performed a fly-by and was then directed to Sioux Falls; the third system was sent to Hawaii, where it performed persistence maneuvers.

In February and June, Near Space Corp. completed the fourth and fifth flights in a series of balloon-based drop tests to qualify **Boeing's Starliner spacecraft parachutes** for crewed flight, part of the effort to return spacecraft directly to U.S. soil. By dropping the Starliner from a high-altitude balloon, the spacecraft is tested with the correct shape, mass, airspeed and altitude, a feat that is difficult to achieve by other means. Early in 2019, Near Space Corp. began working with U.S. and international customers on several **high-altitude projects** and increased the capabilities of its High Altitude Shuttle System, which is a lifting-body-shaped drone that can carry projects to a high altitude for testing.

NASA's Scientific Balloon Program continued work toward its goal of reliably launching **3,500-kilogram or heavier payloads** to altitudes exceeding 35 km. In June and July, the program carried out six training balloon inflations in Palestine, Texas, to investigate prior anomalies. Inflations done under varying weather conditions, gross inflations and with balloons of different sizes stepped through all of the phases of the launch operations up to actual launch. Starting in late August, a Fort Sumner, New Mexico, flight campaign had its first six of 12 planned launches of the **Balloon-Borne Cryogenic Telescope Testbed payload, or Bobcat**. This is a new class of payload looking at the far-infrared emission lines to probe the chemical content, energetics and physical conditions within the interstellar medium of the Milky Way.

In August, CNES, the French space agency, led four scientific **zero-pressure-balloon launches** from the Timmins stratospheric base in Ontario, Canada, including flights with a pointing gondola carrying the French Pathfinder for an International Large Optical Telescope and the Canadian Super-pressure Balloon-borne Imaging Telescope. In May and August, the Swedish Space Corp. performed drop tests from balloons with **dummy reentry bodies** as part of the European Space Agency's **ExoMars mission** that is scheduled to launch in 2020. A 113,000-meter³ balloon with an 800 kg payload and a 330,000 m³ balloon with a 2,000 kg payload carried out two drop tests at the Esrange Space Center. ★

Contributors: *Russ Dewey, Mike Smith and André Vargas*

▲ **NASA tested the Orion** launch abort system in July. Orion is part of NASA's Artemis program and future plans for missions to Mars.
NASA

Space vehicle, automation testing prevalent

BY KARL GARMAN AND ANDY FREEBORN

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

The **Stratolaunch aircraft** was flown for the first time in April in Mojave, California. It set a record for the largest aircraft measured by wingspan, surpassing the 1947 **Hughes H-4 Hercules, or the "Spruce Goose."** Paul Allen, who died in October 2018, founded Stratolaunch Systems to carry rockets for air-launch-to-orbit operations.

Multiple commercial space companies continued testing reusable suborbital vehicles. In May, Blue Origin's **New Shepard** launched for the 11th time from a private site in Texas. This flight, the fifth for this particular reusable booster, reached an altitude of 65 miles. In February, Virgin Galactic's **SpaceShipTwo** completed its second test flight above 50 miles altitude, one of several definitions for the boundary of space. This flight also included the first nonpilot crew member, continuing the company's effort to develop commercial space tourism capabilities. In July, Virgin Orbit tested its **Boeing 747-based satellite launcher**, with the goal of making air launch satellite operations routine. These emerging operations, driven by wealthy individuals from mostly nonaerospace backgrounds, demonstrate the prominent role of nontraditional businesspeople in commercial space.

In July, NASA demonstrated the **Orion spacecraft abort system** during the Ascent Abort-2 test flight at Cape Canaveral Air Force Station in Florida. The test evaluated the Orion capsule's ability to escape from its launch vehicle during conditions of maximum dynamic pressure. Orion is part of NASA's architecture for future space exploration, which includes the Artemis program's return to the moon.

Integrating various levels of autonomy was a consistent theme in atmospheric flight testing. Lockheed Martin's Sikorsky division test flew its **full-authority fly-by-wire UH-60A Black Hawk**. This marked the first stage of Sikorsky's optionally piloted vehicle, with future tests leading toward fully autonomous flight without a pilot on board. Further, a U.S. Air Force and Johns Hopkins University team operated the **Testing of Autonomy in Complex Environments** system to enable artificial intelligence to control various aircraft.

Research efforts to incorporate unmanned aircraft systems safely into the National Airspace System continued. In August, a University of Alaska team tested **UAS beyond visual line-of-sight** without supplemental collision avoidance observers. Also that month, the University of Kansas conducted flight tests to enhance the **collision avoidance capabilities** of UAS while minimizing trajectory perturbations. These projects seek to extend the capabilities of aircraft with varying levels of autonomy, including UAS and urban air mobility flights, or UAMs, over densely populated areas.

Details of various UAM test programs emerged throughout the year. For example, Aurora Flight Sciences first flew its autonomous passenger air vehicle prototype in January, but it crashed in June on its fifth flight. In May, Germany-based Lilium conducted the first untethered flight of its **electric-powered five-seat Lilium Jet**, which the company intends to produce for on-demand air taxi services. UAM projects such as these tend to demand confidentiality, with few details emerging from test programs.

Boeing conducted flight tests on the **737 MAX** aircraft throughout most of the year, evaluating software fixes for the aircraft's control system. The testing centered on software and hardware related to **MCAS**, short for Maneuvering Characteristics Augmentation System, designed to ensure linear control forces at high angles of attack. The testing program is part of requirements to return the aircraft to commercial service following fatal crashes in Indonesia and Ethiopia.

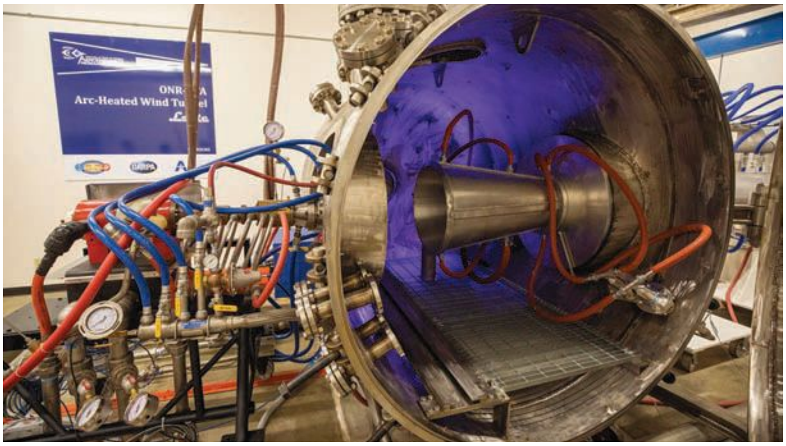
Boeing and Sikorsky, after a first flight in March, continued to expand the envelope of their **SB-1 Defiant compound helicopter**. The design is supposed to substantially increase cruising speed above that of current helicopters. In May, Sikorsky conducted the first flight of its HH-60W Combat Rescue Helicopter, intended to replace the Air Force's HH-60G Pave Hawk. These widely varied programs represent the broad nature of the flight testing field, including new concepts and iterations of established aircraft. ★

Contributors: *Brent Cobleigh, Libin Daniel, Ken Davidian, Shawn Keshmiri, Bruce Owens, Derek Spear and Terry Weber*

Hypersonics research accelerates across 3 continents

BY GREG JOHNSTON AND KEVIN KREMEYER

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.



▲ **The Office of Naval** Research/University of Texas Arc-Heated Wind Tunnel in Arlington provides basic and applied research for arc-jet flow characterization and thermochemical response of thermal protection materials in hypersonic flight conditions. The tunnel, nicknamed "Leste" after the hot and dry winds of the Canary Islands, was brought online in June.
University of Texas at Arlington/ Luca Maddalena

The U.S. Defense Department research enterprise continued to mature hypersonic technologies and concepts through a series of programs executed from within the Office of the Secretary of Defense and in the service branches, consistent with the National Defense Strategy and the **hypersonic modernization** priority of the Office of the Under Secretary of Defense for Research and Engineering.

The **X-60A**, a planned, above-Mach 5 test platform, passed its critical design review in January, clearing the way for fabrication. Generation Orbit Launch Services Inc. is building the X-60A under contract to the U.S. Air Force Research Laboratory's Aerospace Systems Directorate, High Speed Systems Division.

In the civil area, Boeing continued to make progress maturing the design of the **hypersonic passenger airplane and propulsion system** it revealed in June 2018. Progress was also made toward maturing enabling technologies, such as advanced titanium and composite structures, and elements of an integrated propulsion/thermal management/power system.

Hermeus Corp., the Atlanta hypersonics startup, in June began testing the prototype turbine-based combined cycle propulsion system for its proposed **Mach 5 passenger aircraft**.

The University of Arizona completed a 15-inch (38-centimeter) diameter **Mach 5 Ludwieg tube** to facilitate basic and applied research at the test and evaluation scale in August.

In June, the Aerodynamics Research Center of the University of Texas at Arlington brought its newly developed **ONR-UTA arc-heated wind tunnel "Leste"** online. It is equipped with an arc heater producing nominal bulk enthalpies ranging from 1 to 10 MJ/kg at pressures up to 8 atmospheres. The facility is designed to operate with M=2, 4 and 6 nozzle inserts. The M=6 nozzle has an exit diameter of 23 cm.

In Europe, **HEXAFLY-INT, short for High-Speed Experimental Fly Vehicles-International project**, continued to foster international cooperation in civil high-speed air transport research. HEXAFLY-INT, coordinated by ESA-ESTEC, is supported by the European Union within the 7th Framework Programme Theme 7 Transport. This year, the German Aerospace Center, DLR, completed experimental studies in its High Enthalpy Shock Tunnel Göttingen on the **natural boundary layer transition** and the effects of surface imperfections such as steps and gaps on the boundary layer of the **HEXAFLY-INT hypersonic glider**. The 1:2.6 scaled model of the hypersonic glider was tested at Reynolds numbers and Mach numbers that replicated the flight conditions along a section of the HEXAFLY-INT flight trajectory.

Turning to Asia, the Japan Aerospace Exploration Agency in April finished building a subscale hypersonic engine and flight experimental aircraft called **HIMICO, short for High-Mach Integrated Control Experiment**. Propulsion and wind tunnel testing is scheduled at Mach 4 in 2020. The combustion efficiency and heat shield capability of the subscale hypersonic engine was evaluated in September by a direct-connect experiment at the University of Tokyo.

This year in India, the country's first flight test of a **scramjet powered hypersonic technology demonstrator** occurred.

In China, a **Mach 10 hypersonic glide vehicle** was flown in June, launched from a Dongfeng-17 ballistic missile, as reported by the China Aerospace Science and Technology Corp. Also, according to the U.S.-based National Defense magazine, the State Key Laboratory continued efforts to complete its higher-speed detonation-driven hypervelocity tunnel for flows as fast as 12 km/s and Mach 25 with accurate densities, heating surfaces of models with spans as large as 3 meters up to approximately 7,700 degrees Celsius. In April, Xiamen University and the Space Transportation Co. launched a **dual waverider design** with 3D inward-turning inlets to prove the Xiamen Turbine Ejector-Ramjet combined cycle engine which operates from Mach 0 to 6.

Spaceplanes and hypersonic civil transport systems are being developed by countries across the globe. ★

Contributors: *Kevin Bowcutt, Jagadeesh Gopalan, Barry Hellman, Jesse Little, Luca Maddelena, Masataka Maita, A.J. Piplica, Hideyuki Taguchi, Alexander Wagner and Michael White*

◀ Freeriders Stefan Ager, Andreas Gumpenberger and Fabian Lentsch lower themselves by rope from an airship to begin their descent of 2,200-meter Austrian peak Kleiner Valkastiel.
Mirja Geh and Lensecape Productions

No "flight shaming" here: Airships leverage eco-friendliness

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.

This may go down as the year **"flight shaming"** really got off the ground. In September, Alexandre de Juniac, head of the International Air Transport Association, called the trend — in which environmentally concerned travelers choose **trains over planes** — the biggest threat to air travel in Europe and said it would spread to the United States and other developed countries. Against this backdrop, advocates for airships and airship-related ventures sang the environmental merits of lighter-than-air systems. Carried aloft more by lifting gas than motors, airships leave a dainty carbon footprint. Moreover, their lift and surface area make them promising candidates for electric and solar-electric propulsion.

In April, England's Hybrid Air Vehicles Ltd. announced it would explore electric propulsion via a partnership with Collins Aerospace and the University of Nottingham, with funding from the United Kingdom Aerospace Research and Technology Program. The objective of the project, named **E-HAV1**, is to deliver a **full-sized prototype 500-watt electric motor** for ground testing and eventual use on a production model Airlander 10.

Swedish travel company OceanSky said in June it had selected **Airlander 10** as its preferred platform for environmentally friendly trips to the North Pole starting in 2023. Up to 16 passengers would make a three-day passage from an archipelago in Norway to the North Pole and back, landing at the pole. Priced at some $79,000 per double-occupancy cabin, the trips, according to OceanSky CEO Carl-Oscar Lawaczeck, will appeal to travelers wanting to contribute to "the development of sustainable travel."

In July, a team led by the International Institute for Applied Systems Analysis published in the journal Energy Conservation and Management a scheme for using airships to usher in a hydrogen economy. A fleet of automated, unmanned, **hydrogen-filled cargo airships would circumnavigate the Earth** with the jet stream for propulsion. On landing, they would offload their cargo and about 80% of their hydrogen (for terrestrial fuel) and then fly home to pick up more freight. Lead author Julian Hunt notes the plan would eliminate the expense and energy cost of having to liquefy hydrogen for transport.

This year saw the birth of **Zeppelin-skiing**. In March, three freeriders (one snowboarder and two skiers) flew by Zeppelin from Germany to Austria, where they hovered over the 2,200-meter Kleiner Valkastiel peak. They shimmied down a 50-meter rope, alighted on the mountain and began their downhill run. Lensecape Productions captured it all on a four-minute video, which was **viewed 6 million times**.

Defense and border-protection agencies showed new commitment to flying tethered aerostats for data collection and surveillance. Maryland-based TCOM in September announced it had won a $979 million contract from the U.S. Department of Defense to support **Army aerostats**, including 23 deployed in Afghanistan, Iraq and North Africa. ILC Dover built new envelopes for the U.S. Customs and Border Protection agency's **Tethered Aerostat Radar System**, delivering two of 420,000 cubic feet (12,000 cubic meters) each and a third of 275,000 cubic feet (7,700 cubic m).

Helium prices spiked for the third time since 2006, creating **gas shortages**. Phil Kornbluth, president of Kornbluth Helium Consulting, in August predicted shortages would persist through the end of 2019 and then would ease somewhat, owing to increased production.

The year marked the 90th anniversary of the **Graf Zeppelin's around-the-world flight**, which set records for distance and duration that still stand, and the 100th anniversary of R34's double-crossing of the Atlantic (complete with stowaway and cat). ★

Future vertical lift competition intensifies; eVTOL designs proliferate

BY ERASMO PIÑERO JR.

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

In a major vertical or short takeoff and landing technology push as part of its modernization plans, the U.S. Army awarded contracts in April to **five future attack reconnaissance aircraft** competitive prototypes. It was the start of a large Department of Defense VSTOL acquisition program not seen since the early days of the X-35 Joint Strike Fighter concept demonstrator program. The companies are: AVX Aircraft, partnered with L-3 Communications Integrated Systems, both of Texas; Bell Textron Inc. of Texas; Boeing; Karem Aircraft of California, partnered with Northrop Grumman and Raytheon; and Sikorsky. Each candidate was to receive approximately $15 million this year and in 2020.

Sikorsky continued progress on its **SB>1 Defiant** joint multirole technology demonstrator, conducting the **first flight** of the aircraft in March at Sikorsky's Flight Research Center in West Palm Beach, Florida. Sikorsky is partnered with Boeing on the SB>1, which is aimed at fulfilling the Army's need for the future long-range assault aircraft. The **S-97 Raider** also continued to make progress, getting 55 hours of flight testing. **Bell V-280 Valor** tilt-rotor demonstrator testing continued apace, surpassing 100 flight hours and achieving a speed of 300 knots true air speed in March, proving the high-speed capabilities inherent in tilt-rotors.

This year saw the proliferation of **pilotless vertical takeoff and landing vehicles** for both private use and commercial transportation. In early September, the online World eVTOL Aircraft Directory, sponsored by the Vertical Flight Society, added its 200th electric vertical takeoff and landing aircraft concept. The directory was launched in 2017 and has since been tracking new electric and hybrid/electric-powered VTOL aircraft in development by aerospace companies, entrepreneurs and inventors around the globe.

In June, at the third annual Uber Elevate summit in Washington, D.C., mock-up concepts generated excitement in the media and the public. It was an opportunity for the air taxi or **urban air mobility** players to show their future products that they say will eventually meet the demands of urban air vehicles at costs far below traditional helicopters. Boeing subsidiary Aurora Flight Sciences conducted the **first flight of an eVTOL prototype for urban air mobility** in January. The vehicle is configured as an all-electric, four-seater with nine rotors.

The **F-35 program** began a period of intensive production in 2018, but one of its production partners, Turkey, was no longer involved as of July. The 2020 fiscal year budget approved by Congress in May authorized the purchase of 94 F-35s, 16 more than requested. The F-35C, the U.S. Navy carrier-based version, reached initial operational capability at the end of February, accomplishing what the three services set out to do in 2001.

Four Bell-Boeing **MV-22B Osprey** tilt-rotor aircraft from Marine Medium Tiltrotor Squadron 268 completed a trans-Pacific flight from Okinawa, Japan, to Marine Corps Base Kaneohe Bay, Hawaii, in May, demonstrating the long reach and operational maturity of the V-22. The aircraft flew more than 5,300 nautical miles with minimum scheduled stops to refuel. ★

***Contributors:** Mark Alber, Paul Bevilaqua, Geoffrey Jeram, Mike Hirschberg and Paul Park*

▶ **Sikorsky conducted** the first flight of the SB>1 Defiant joint multirole technology demonstrator in March.

Sikorsky

▼ **The Bell V-280 Valor** tilt-rotor demonstrator this year achieved a speed of 300 knots true air speed.

Bell Textron

Industry disruption, transformation continue into fifth year

BY TOM BUTASH

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

A frame from the video feed of SpaceX Falcon 9 upper stage shows a stack of 60 Starlink smallsats moments before they're deployed. SpaceX

Satellite operators curtailed **geosynchronous satellite orders** in 2019 for a fifth consecutive year, a trend driven by overcapacity and falling prices in many markets, ongoing advances in and additions to planned non-geosynchronous orbit megaconstellations, and persistent market uncertainties. The specter of **50,000 NGSO broadband smallsats** (satellites with mass less than 1,000 kilograms) planned for launch over the next decade — promising even greater capacity — further motivated GSO operators to delay or cautiously restrict additional investments in their fleets. This, in turn, led to the restructuring of GSO satellite manufacturing stalwarts, including Maxar Technologies (formerly SSL) and Thales Alenia Space. The downturn also prompted the acquisition of AsiaSat, Avanti and Inmarsat by private equity interests; other operators, including APT Satellite and Sky Perfect JSAT, examined alternative business models.

In March, Northern Sky Research reported that **capacity prices declined 18%** over the preceding year, extending declines of 35% to 60% incurred over the prior two years. The price declines were once again attributed, in part, to additional high-throughput satellite launches. Exacerbating these challenging market conditions, advances in planned NGSO broadband megaconstellations were seen throughout the year. In February, **OneWeb** launched the first six of its 648 smallsat constellation, while in May, SpaceX launched the first 60 of its ultimately 42,000 smallsat **Starlink constellation** and another 60 in November. Further increasing prospective capacity, **Amazon's Kuiper Systems** in July filed an application for FCC approval of its 3,236 satellite NGSO constellation comprised of 784, 1,296 and 1,156 smallsats at 590-kilometer, 610 km and 630 km orbital altitudes, respectively.

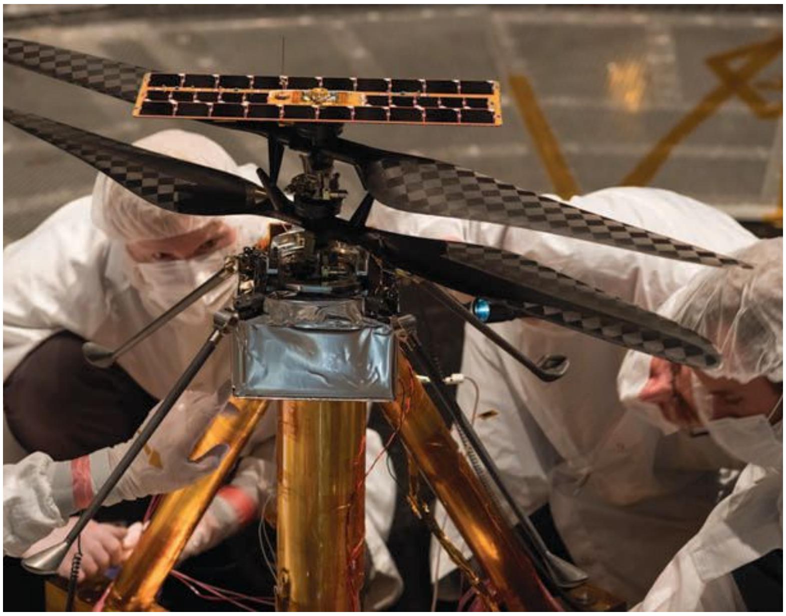
Against this backdrop, unsurprisingly, only **seven competitive, commercial GSO orders** were recorded as of the end of October, suggesting a year-end total of eight orders — an extension of the depressed orders trend that began in 2015. Commercial GSO satellite orders totaled 19, 15, eight and five in 2015, 2016, 2017 and 2018, respectively, after averaging 26 per year during the three years prior. Six additional GSO orders were received for military applications, some from commercial operators, suggesting a convergence of the commercial and military markets.

In response, the industry increased its focus on an emerging class of small broadband communications satellites, or **"micro-GSO satellites,"** designed to fill capacity gaps too small to justify the time, expense and risk of deploying a traditional 4- to 8-metric-ton GSO communications satellite. Development of these 250 kg to 2,000 kg micro-GSO satellites was ramped up by startups Astranis, GapSat, Saturn Satellite Networks and the SWISSto12-Tyvak partnership and by established manufacturers including Maxar (which received an Ovzon-3 order) and Boeing. This trend partially offset the decline in conventional GSO orders.

In August, Northern Sky Research reported that at least 16 companies, including Astrocast, Fleet, Kepler, Lacuna Space, Myriota and Sky and Space Global, were developing **NGSO constellations of between 32 and 200 cubesats** (the body dimensions of which are low multiples of 10-centimeter cubes) to provide **"internet of things" communications services** in remote markets. Although the revenue from these activities represents a small fraction of recent GSO market sales declines, the initiatives nonetheless demonstrate the industry's willingness to innovate to cost-effectively address emerging opportunities.

Supporting this innovation, the launch vehicle industry, led by SpaceX and smallsat launch vehicle developer Rocket Lab of California, continued to **drive costs lower**, reducing the expense of installing additional communications satellite capacity. As of mid-November, SpaceX had conducted nine Falcon 9 and two Falcon Heavy launches in which booster stages were routinely recovered. Rocket Lab conducted five Electron smallsat launches in this timeframe and, perhaps encouraged by SpaceX's success, announced in August that it was developing a reusable booster. During this pivotal month, SpaceX revamped its **smallsat ride-share program**, lowering launch costs to $5,000 per kilogram, about 20% of the rate that had prevailed for decades. Inasmuch as estimates indicate as many as 100 smallsat launch vehicles are under development worldwide, the costs of space access and providing additional communications satellite capacity will undoubtedly continue to decline. ★

Contributors: *Chris Hoeber and Roger Rusch*



▲ **NASA's Mars Helicopter flight model** — the aircraft going to Mars with the 2020 rover — at the Jet Propulsion Laboratory.
NASA

Transformations in computer architecture enable advances in exploration autonomy

BY RICK KWAN

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

The architecture of terrestrial computing is in a metamorphosis that could eventually prove useful in planetary exploration. At its core is the rapid adoption of data science — not only by scientists and engineers but even by retailers sitting on stockpiles of business data. And the underlying statistics and linear algebra increasingly employ shorter precision arithmetic and logic for greater speed.

The **fastest supercomputer** on the Top500 list in 2019 was the U.S. Department of Energy's **Summit** at Oak Ridge National Laboratory in Tennessee. Introduced in June 2018, Summit is built on a combination of **IBM POWER9** central processing units and **Nvidia Volta** graphics processing units and is rated on High Performance Linpack at 148.6 petaflops. Beyond physics simulation, the Volta GPUs are positioned for machine learning and artificial intelligence research through the use of small integers.

The vectors and matrices of data science and machine learning aren't necessarily single- and double-precision floating points. Much of it can be done with half-precision 16-bit floats and small 8-bit and 4-bit integers. For a given area of silicon and power budget, smaller precision allows for greater parallelism, hence increased speed.

This highly parallel reduced precision is employed in several low-end neural processing unit or tensor processing unit products released in the past 12 months. The **Nvidia Jetson AGX Xavier 8G** was available in August, and the **Google Edge** tensor processing unit was released in March. Some are targeted at mobile platforms such as drones, rovers and autonomous cars. Tesla Motors began shipping its own **"Full Self-Driving" chip** in March.

The **neural processing** and **tensor processing** units are an evolution of graphics processing units, which a decade ago morphed into physics engines and provided a radical boost for modeling and simulation. Neural processing units and tensor processing unit chips will eventually lead to more advanced autonomy in planetary explorers.

Summit is designed to facilitate both physics simulation and **artificial intelligence** research. In June, Oak Ridge reported that a Monte Carlo simulation of a modular nuclear reactor ran 30 to 40 times faster on Summit than on the Oak Ridge's **Titan supercomputer** introduced in 2012. It also ran the largest cosmological simulations to date, providing comparison data for the Large Synoptic Survey Telescope, still under construction.

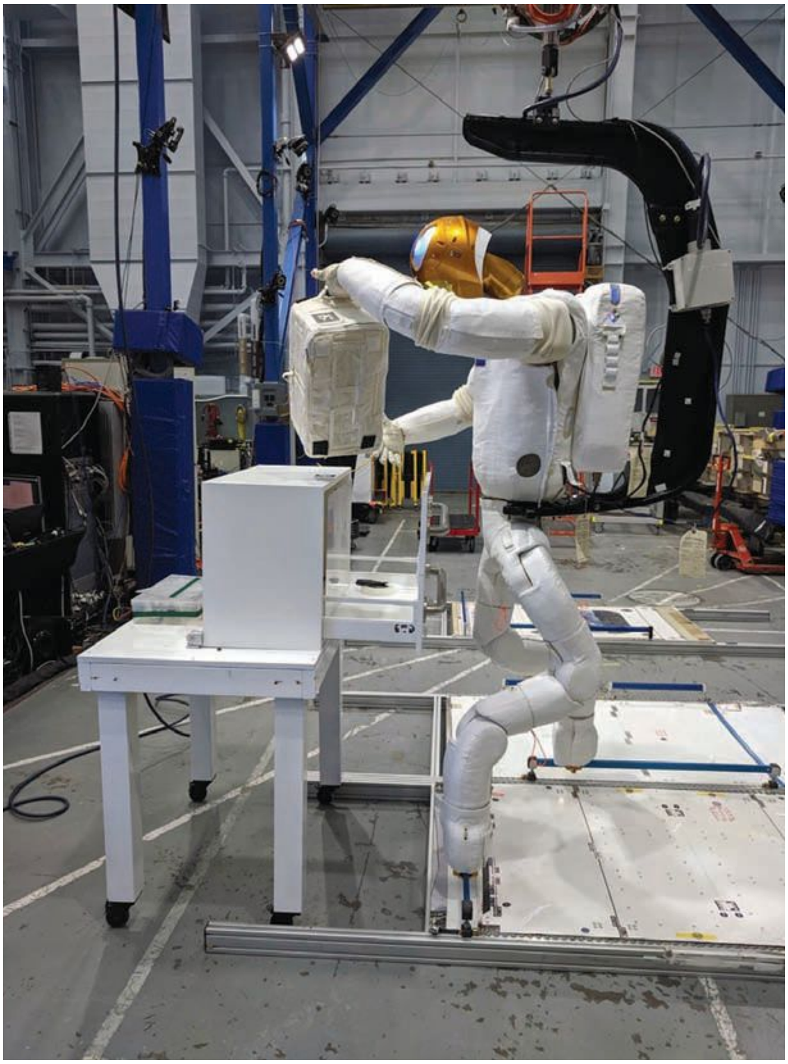
Summit also ran **large computational fluid dynamics simulations**. Reported at the AIAA Aviation Forum in June, the FUN3D simulator was used to run a CFD job of **6.5 billion elements and 200,000 time steps**. It previously took 2.9 months on a system of 5,000 Xeon Skylake CPU cores. On Summit, using 552 Tesla V100 GPUs (a fraction of what Summit has available), it took four days — a **20-times speed-up**. To get the same speed-up with CPUs would take 112,500 Xeon Skylake cores.

Meanwhile, spacecraft computers are finding their way onto atmospheric flyers. In August, NASA's dual-rotor **Mars Helicopter** was attached to the belly of the Mars 2020 rover. It is expected to make several test flights in the sparse Martian atmosphere and give operators a perspective of rover surroundings that was not previously possible. The avionics stack includes a **Snapdragon** flight processor, **TI Hercules** high-reliability microcontroller and **ProASIC** rad-tolerant field programmable gate array. In June, NASA selected the **Dragonfly** rotorcraft to explore Titan, a Saturnian moon with thick atmosphere and low gravity. A **radiation-hardened RAD750** computer will control the avionics of this flying laboratory. As with Earth-based drones, a tight control loop of sensors, CPU and actuators must adjust the vehicle's flight in real time and follow a mission profile. But these flights are after months or years of dormancy in space and targeting different environmental extremes. ★

Testing autonomy for lunar Gateway, Robonaut 2 and aviation

BY NATASHA NEOGI

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



▲ **Robonaut 2, shown** performing a simple task, may be on its way back to the ISS.
NASA

In preparation for its return to the moon in the **Artemis** program, NASA demonstrated the ability of the lunar Gateway to integrate with spacecraft, such as the Orion capsule and the human lunar lander, and tested **autonomy technology** in managing the Gateway's vehicle systems in September at NASA's Johnson Space Center in Houston. Autonomy will play an important role in operating the **Gateway** with its reduced data downlink capacity, communication delays, and the combination of crewed and uncrewed periods of operation. The September demonstration tested a surrogate vehicle's ability to prioritize what data is most important for the ground to receive based on the activities taking place and the health of the vehicle. The Gateway and vehicle will also respond to failures with additional safety-oriented actions, compared to those seen on the **International Space Station**. Autonomy will enable the vehicle to assess the available resources and system statuses, return to a more functional state, and adjust future activities. The combination of these capabilities will free up the crew and ground staff to focus on the most critical tasks.

Additionally, two technology development demonstrations at Johnson were aimed at future **Robonaut 2 autonomous logistics** aboard the ISS. The first demonstration, in June, focused on the challenges inherent in operating a robot aboard the ISS from the ground at Johnson. These include communication latency, bandwidth restrictions and expected losses of signal. Operators from a remote mission control operated Robonaut 2 while performing numerous autonomous tasks such as planning and taking steps across ISS handrails, locating and posing in front of objects, and interacting with those objects. A demonstration at Johnson in September focused on **increasing the robot's autonomous interaction in and around variable environments**, including mapping unknown obstacles and traversing around them, building robust object detection, and working with those objects in a cluttered environment.

In aviation, the **Automatic Ground Collision Avoidance System**, which has a set of autonomous decision-making and collision-avoidance algorithms to prevent jets from flying into the ground, was recommended for installation on the U.S. Air Force variant of the **F-35 Lightning II** this year — five years ahead of initial plans.

In June, the **American Society for Testing and Materials** published its first technical report, "Autonomy Design and Operations in Aviation: Terminology and Requirements Framework (TR1-EB)," to guide the development of **standards associated with increasingly autonomous flight**. Administrative Committee 377, comprised of four aviation-related society technical committees, prepared the report, which provides definitions related to automation, autonomy, artificial intelligence, machine learning and many other relevant terms. It also discusses the potential for levels of automation for aviation. The report will help standards committees produce a consistent and cohesive body of standards by providing common terminology and a holistic framework for discussing and determining requirements for increasingly autonomous systems. ★

Contributors: *Kerianne Hobbs, Andrew Lacher, Elizabeth Taylor and Alex Sobey*

Artificial intelligence and hypersonic weapons drive sensing, fusion research

BY RAYMOND S. SWANSON AND KENT R. ENGEBRETSON

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.

In February, the Pentagon released its **artificial intelligence strategy** with the **Joint Artificial Intelligence Center** at the head of the effort. The Pentagon indicated that the Defense Department will implement AI into existing processes, digitization and smart automation. The document urges action "to protect our security and advance our competitiveness" in developing safe, ethical and secure AI solutions. The strategy says that JAIC will work with government, private sector, academia and international partners.

AI has reshaped the sensing landscape. In June, a new Lux Research report titled "Intelligent Sensing: The Impact of AI on Sensor Capabilities" identified the impact of AI on a range of sensor types, including optical, mechanical and acoustic sensors through analysis of more than 130,000 patents since 2012.

"With the advent and proliferation of **artificial intelligence technologies** — concentrated in machine learning — the capabilities of software-defined sensors are increasing at a breakneck pace," Cole McCollum, research associate in sensors at Lux and lead author of the report, said in an article. "AI for analyzing sensor data enables far more robust predictions and classifications using sensor signals compared to other methods like physics-based models. We are already seeing this innovation potential with the development of applications ranging from medical diagnosis to predictive maintenance."

The greatest concentration of growth in new sensors is in consumer applications with the most activity in **optical sensing** across all applications. The other primary sensing emphasis has been on development of and defense against **hypersonic weapons**. The high speed and unpredictable maneuverability of these weapons creates a difficult challenge for existing sensing architectures. Concerned with the rising threat of hypersonic weapons from China and Russia, the U.S. Missile Defense Agency in 2018 awarded contracts for concepts regarding the **Space Sensor Layer**, which detects and tracks hypersonic threats from birth to death. In April, MDA asked Congress for an additional **$108 million for hypersonic and ballistic space sensor development** in fiscal 2020. The newly established **Space Development Agency**, working collaboratively with MDA on the Space Sensor Layer, revealed in June its fiscal 2020 plans for a proliferated low Earth orbit satellite constellation that would consist of about **1,200 satellites across five layers**: a 200-satellite custody layer, a 658-satellite space transport layer, a 200-satellite tracking layer, a 200-satellite deterrence layer and three advanced maneuvering vehicles. The space layer will require not only increased sensor capabilities but also AI and improved communications to process data and provide battle management recommendations to commanders.

In addition to defense against hypersonic weapons, development of hypersonic weapons also poses significant sensing challenges. In June, DARPA issued a solicitation for the **Extreme Environment Sensors project**. The goal is to develop and validate robust distributed instrumentation systems capable of withstanding the extreme heat, shock and vibration of hypersonic flight. ★

The Air-Launched Rapid Response Weapon is a hypersonic weapon prototype in development by Lockheed Martin under contract to the U.S. Air Force.
Lockheed Martin

New focus on safety in software

BY HANNAH LEHMAN

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

If there were a theme for software this year, it would be an increased focus on safe autonomy and cybersecurity.

Following the trends of previous years, military and commercial industries continued to increase investment in autonomy, especially **learned autonomy**. In March, Kratos' autonomous fighter jet, the **Valkyrie**, completed its first flight. This was the first stage in an initiative to allow pilots to focus on more critical items by making **fully autonomous fighter jets** that can process large amounts of data rapidly without the human getting inundated with information. In May, **Boeing's Tapestry Solutions** won a U.S. Air Force contract worth as much as **$259 million** for software that will help troops plan missions, including points for weapon launches. And in July, the Air Force increased focus on autonomy as its **tanker planning software**, designed to increase reliability in refueling, moved into testing.

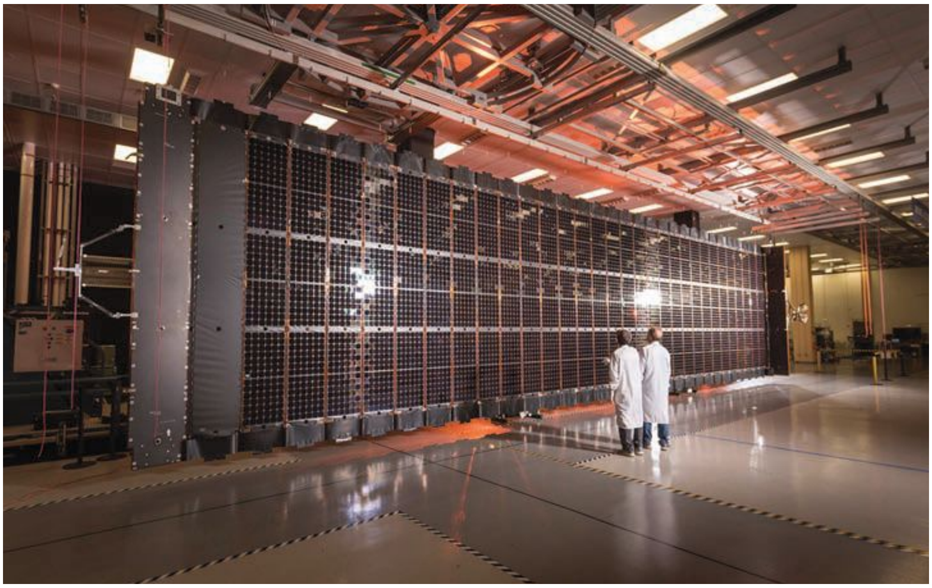
The past year also saw more focus on **cybersecurity** in light of developments in airline vulnerability. The importance of hacking prevention was demonstrated in July when the U.K. Information Commissioner's Office said it would **fine British Airways 183.39 million British pounds** ($225 million) for a 2018 data breach that affected half a million of the airline's customers. In March, **technical issues in American Airports Corp.'s air-booking computers** caused widespread delays. Though the problem was resolved, and computers were up within the hour, the incident further emphasized the importance of safety and redundancy in airline software.

Since 2010, the Air Force has been spearheading the military's **only jam-proof satellite network**, the **Advanced Extremely High Frequency** system. Through its work with the AEHF, the Air Force has amassed experience to begin production of a newer, cheaper, jam-resistant satellite communication framework. In August, the Air Force launched the fifth AEHF satellite.

A discussion of aerospace software would be incomplete without mentioning the **Boeing 737 MAX 8**. In the span of six months, two 737 crashes resulted in 346 deaths. The crashes implicated **MCAS**, short for Maneuvering Characteristics Augmentation System, a program designed to prevent stall. Though both aircraft that crashed had other initial failures in sensing and deriving the angle of attack, the crashes brought to light issues with implementing MCAS on the 737 MAX aircraft. After the planes were globally grounded in March, Boeing worked to create a software patch to prevent the problem from reoccurring. As of November, the planes were tentatively scheduled for a "phased ungrounding" and reintroduction into commercial air transit. The crashes and eventual pinpointing of the problem led to awareness about the **FAA's regulatory practices**, putting increasing pressure on primary, interdependent safety reviews of all critical components in commercial aviation.

On a lighter note, 2019 marked the 50th anniversary of the **Apollo 11** moon landing. As July 20 rolled around, NASA reflected on the software that assisted Neil Armstrong and Buzz Aldrin in bringing the Eagle lunar lander down safely. A lot has changed since the 1960s in the software world. Computers no longer take up an entire room, embedded systems no longer have to be coded entirely in assembly, and in the 1980s, microprocessors were invented. However, the underlying purpose behind software remains the same. Just like the engineers of Apollo 11, engineers today strive to create efficient programs that assist humanity and make activities enjoyable, reliable and safe. ★

▼ **U.S. airline pilots are** expected to be training on full motion simulators such as CAE's 7000XR Series once new software is approved for Boeing's 737 MAX aircraft.
CAE



▲ **The Multi-Mission Modular Solar Array**, unfurled at Lockheed Martin's Sunnyvale, Calif., factory, powers the LM 2100 satellite bus.
Lockheed Martin

Radioisotope and solar-powered missions to Mars, moon, GEO

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.

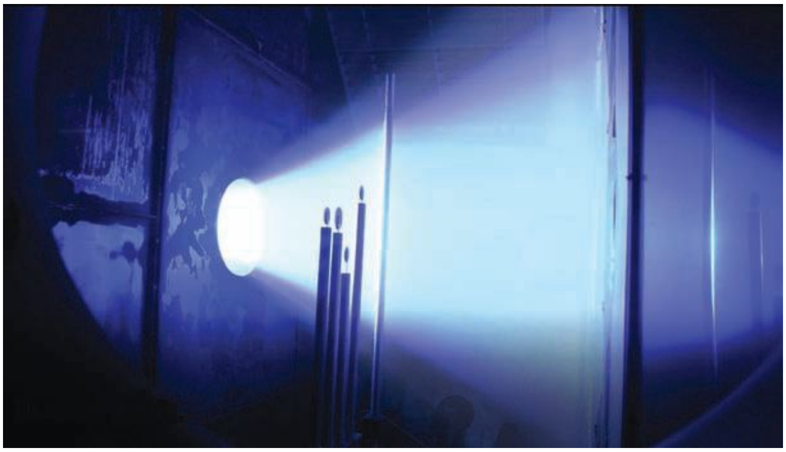
NASA gave the U.S. Department of Energy the go-ahead in July to fuel the Mars 2020 rover's **Multi-Mission Radioisotope Thermoelectric Generator** with plutonium dioxide in preparation for the launch to the red planet in July 2020. The MMRTG's total mass is about 45 kilograms, of which 4.8 kg is plutonium dioxide — the source of the steady supply of heat to convert into electricity for storage in two lithium-ion rechargeable batteries. The electrical power system on the **Mars 2020 rover** produces about 110 watts at launch and will decline a few percent per year for a 14-year operational life. Unlike with solar panels, with the MMRTG engineers get the flexibility to operate the rover's instruments at night, during dust storms and through the winter.

Aboard the Mars 2020 rover as one of the science payloads is the solar-powered **Mars Helicopter**, which was attached to the belly of the rover in August. The drone has a mass of 1.8 kg and will demonstrate flight stability on the surface of Mars and scout the best driving route for the rover. Solar cells will recharge its batteries, which are six lithium-ion cells with a nameplate capacity of 2 ampere-hours.

The first **European Service Module**, built by Airbus Defense and Space, was mated to NASA's **Orion crew module** in July. Built by Lockheed Martin Space, the Orion is attached to the front of the service module. The combined assembly was to undergo critical thermal-vacuum testing in late 2019 at NASA's Plum Brook Station in Ohio and return to Kennedy Space Center in Florida in early 2020 to begin launch preparations, including installation of the **four solar array wings**. The electrical power source on the European Service Module consists of four solar array wings comprised of three solar panels per wing. The solar array wings provide approximately 11.2 kilowatts of total power at 120 volts. The solar cells are the latest **triple-junction technology**, provided by New Mexico-based SolAero Technologies. The solar array orientation is controlled by the two-axis solar array drive mechanism, which can swivel between minus 35 degrees and plus 25 degrees on the inner axis and rotate fully from 0 to plus 360 degrees on the outer axis to sun-track for maximum power. The four wings are folded against the crew module adapter of the service module during launch and extend out 7 meters after launch into low Earth orbit. A **Space Launch System** rocket will launch the Orion spacecraft on the uncrewed **Artemis-1** mission around the moon, targeted for before the end of 2020.

Lockheed Martin's **A2100TR satellite bus** with fourth-generation 25-kW **Multi-mission Modular solar Array, or MMA**, launched and deployed on orbit in February on the **SaudiGeoSat-1/HellasSat-4** communications satellite, designed for 15 years of on-orbit operation. SaudiGeoSat-1/HellasSat-4 has electric propulsion Hall Current thrusters powered by the MMA to transfer the satellite to its geostationary final orbit. The orbit transfer after launch was completed on schedule, and the satellite was to enter service in late 2019 at its assigned orbit at 39 degrees east longitude. In addition to this mission, a second commercial A2100TR satellite also powered by the MMA, Arabsat-6A, was launched in April on the first Falcon Heavy booster with a commercial payload. This satellite also used a 25 kW version of the MMA, modularly designed to support both lower- and higher-power satellite configurations. As of the beginning of October, this satellite was also operating nominally in its assigned orbit and was to enter service in late 2019. A third lower-powered 13 kW MMA variant was scheduled to launch in December at the earliest on an A2100TR satellite, JCSat-17. ★

Contributors: *John Gibb and Scott Billets*



Explosive growth in electric propulsion

BY JAMES SZABO

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

▲**A 100-kilowatt plasma plume** from Ad Astra's Variable Specific Impulse Magnetoplasma Rocket engine is measured with a series of probes.
Ad Astra Rocket Co./AASEA

As the year began, the European Space Agency's **BepiColombo spacecraft** continued toward Mercury, propelled by QinetiQ gridded ion thrusters. The power processing units were developed by Airbus-Crisa. BepiColombo was launched in 2018 and is scheduled to arrive at Mercury in 2025. Also early in 2019, a **BHT-200 Hall effect thruster, or HET**, built by Busek Co. of Massachusetts entered operational status on the FalconSat-6 satellite, launched in December 2018.

In February, four **Aerojet Rocketdyne XR-5 HET strings** were launched on Hellas-Sat. In August, another four XR-5s were launched on Advanced Extremely High Frequency-5. Arabsat 6A, launched in April, and another geostationary spacecraft launched during the year will both employ **Aerojet Rocketdyne hydrazine Arcjets** for North-South station keeping.

Also in February, OneWeb Satellites launched its first six spacecraft out of hundreds planned. OneWeb's **low-power electric propulsion system**, conceived by Airbus, features xenon HETs and innovative electronics and propellant regulation systems. The electric propulsion subsystem is also part of the Arrow platform used for other Airbus applications. In May, the **SpaceX Starlink constellation** began to take shape with the launch of 60 operational satellites propelled by **krypton-fueled HETs**. SpaceX has received FCC approval to launch thousands more.

High-power electric propulsion will soon become part of NASA's human exploration program. NASA's Power and Propulsion Element, the first planned element for the lunar Gateway, will carry two **Aerojet 13-kilowatt Advanced Electric Propulsion System HETs** and four **Busek 6-kW HETs**. In May, NASA awarded the Power and Propulsion Element contract to Maxar Technologies. In August, the 13-kW thruster was tested at full power. Launch was scheduled for 2022.

Accion Systems Inc. of Massachusetts set a record for its **electrospray thruster chip technology** by firing a test unit for about 2,500 hours without intervention, achieving approximately 100 newtons of total impulse. The test concluded in May. Midyear, two of Busek's **small capillary-driven BET-300-P electrospray thrusters** each exceeded 70Ns of total impulse, with the second test finishing in September.

In July, an electric propulsion system integrated test was completed for the Psyche mission. The **Maxar-Jet Propulsion Laboratory spacecraft**, which is scheduled for launch in 2022, will use a **modified SPT-140 HET** system to rendezvous with the asteroid 16 Psyche in 2026.

In September, Aerojet Rocketdyne and subcontractor ZIN Technologies of Ohio finished assembling the first flight string of the **7-kW NEXT-C gridded ion engine** system. In 2021, NEXT-C will fly on NASA's **Double Asteroid Redirect Test**, managed by the Johns Hopkins University Applied Physics Laboratory.

Also in September, Ad Astra Rocket Co. started a **Variable Specific Impulse Magnetoplasma Rocket, VX-200SS**, testing campaign, completing a thermal steady-state 100-kW milestone. Ad Astra also bench-tested to full power a **120-kW Technology Readiness Level-5 power processing unit** from Aethera Technologies of Canada, measuring 98% direct-current-to-radio-frequency efficiency.

Researchers at the University of Tokyo previously reported developing and testing a three-unit cubesat called AQT-D equipped with a 1U water Resistojet system called AQUARIUS. In September, **AQT-D** was launched to the International Space Station.

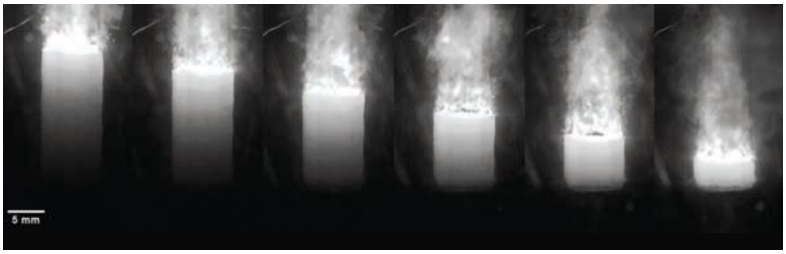
NASA's Jet Propulsion Laboratory in California is developing the **Ascendant Sub-kW Transcelestial Electric Propulsion System, or ASTRAEUS**, small satellite HET system for interplanetary missions, targeting a throttle range of 150 to 1,000 watts and 100-kilogram xenon throughput, peak system efficiency greater than or equal to 50%, and dry mass less than or equal to 10 kg for the thruster, PPU, flow controller and gimbal. Meanwhile, a Busek BHT-600 HET duration test accumulated 6,300 hours at 600 W through November, demonstrating 860 kilonewtons of total impulse and 60 kg of xenon throughput.

In November, Busek delivered the first low-power, iodine-fueled, gridded ion thruster flight system. Two more were scheduled for delivery before the end of the year.★

Innovations made on NASA initiator, 3D printing of propellants, cool gas generators

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.



This strand of solid propellant was manufactured with Purdue University's vibration-assisted printing technique. It's shown burning at 10.34 megapascals with 300 milliseconds between the frames.
Purdue University

Changes to the production process for **NASA standard initiators** or NSIs, are never made lightly. NSIs provide the initial pulse to begin critical thermal and mechanical processes in both human-rated and uncrewed missions. For example, the "seven minutes of terror" required for landing a rover on Mars depends on the NSIs functioning perfectly.

The first NSI production lot utilizing a new automated manufacturing process was acceptance-tested and delivered to NASA's Johnson Space Center in Houston in September by Chemring Energetic Devices of Illinois. CED completed the qualification program in late 2018 to become the only certified NSI producer in the world.

The company's qualification included implementation and verification of new manufacturing technology. **Robotics** were employed for **bridgewire welding and energetic printing**, which eliminated the traditionally operator-dependent processes and improved manufacturing safety. Test results showed the new process significantly increased the manufacturing uniformity and reduced the performance standard deviation, especially in the actuation timing at minus 251 degrees Celsius. Turning to **additive manufacturing for solid propellant fabrication**, these techniques enable structural and compositional gradients that can improve combustion performance. However, until this year, additive technologies were only compatible with materials whose oxidizer mass fractions were less than 60 volume %. Research by Purdue University this year led to the development of a new additive technique called **vibration assisted printing** or VAP. This direct-write technique has removed prior material limitations. The Purdue group demonstrated in January the additive manufacturing of solid propellants with oxidizer volume fractions in excess of 76 vol.%. Furthermore, these material systems were 3D-printed at high rates with fine layer resolution (approximately 100 microns) and tailorable combustion characteristics. The adopted approach eliminates many of the hurdles commonplace in the industry and can be a transformative fabrication tool, while also supporting new research in materials development.

The holy grail for **metal particle combustion** would be to harness the enormous chemical potential energy stored within metal fuel particles at time scales relevant to a detonation event. Diffusion controlled reactivity limits aluminum's energy release potential but with the development of nanoparticles, time scales for diffusion-controlled kinetics could approach detonation. Nanoparticles cannot achieve reactivity at detonation time scales by themselves. This year, researchers at Texas Tech University and the U.S. Army's Aberdeen Proving Ground in Maryland continued improving the detonation time scales. They did this by capitalizing on a 2018 process breakthrough in which they transformed the inert alumina passivation shell surrounding the aluminum core into a highly oxidizer-rich salt called **aluminum iodate hexahydrate**, or AIH, through surface chemistry. In May, the Texas Tech and Aberdeen team prepared the aluminum particle surface with plasma surface treatments prior to AIH surface chemistry. The plasma etches the surface layer so that AIH formation and concentration are more controlled and repeatable. Plasma surface treatment improves the particles' safe handling and stability under ambient conditions by producing a more consistent and repeatable coating. AIH-coated Al particles improve the detonation velocity of TNT by 30%.

In July, ExxFire of the Netherlands finalized installation of 105 of its **fire-suppression systems** at Zee Media in New Delhi — the largest shipment ever and a clear vote of confidence from the market. Zee Media is the largest streaming media company in India and part of the Essel Group. The ExxFire systems use **cool-gas generator technology** from the Netherlands Organisation for Applied Scientific Research, or TNO, for suppressing fires in closed volumes such as server racks and switching cabinets in production facilities. The extinguishers produce nitrogen gas that lowers the oxygen level and suffocates the fire. While today's high-pressure cylinders require maintenance, ExxFire's cool-gas generators store nitrogen gas in solid form in unpressurized cylinders requiring no maintenance. ★

Contributors: *Steve Son, Emre Gunduz, Michelle Pantoya, Hobin Lee and Harm Botter*

Record-setting engine technologies pave way for third era of aviation

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.

Gas turbine engine manufacturers continued developing technologies to improve engine performance and durability and to reduce maintenance and environmental impact this year, setting many records along the way.

In June, Pratt & Whitney of Connecticut completed an accelerated endurance test to assess **PW1100G geared turbofan engine hot-section durability**. Half of the new airline passengers over the next 20 years are expected to come from the equatorial and Asian region, an area of significant atmospheric dust and pollutants that affect engine life. Pratt & Whitney's newly developed severe environment testing in West Palm Beach, Florida, coupled with modeling technology, expedited design enhancements by duplicating damage observed in three to four years of flight time on the Airbus A320neo with just three months of testing. An average loading of dirt, determined by examining thousands of flights, **replicated realistic severe operating conditions**. Dirt supplied at these concentrations mimics flight exposure, especially in the eastern equatorial region of the world, specifically in Africa, Middle Eastern countries, India, China and the Pacific Islands.

▼ **The Passport engine** from GE Aviation was installed on a Bombardier Global 7500 that set several speed records.
GE Aviation

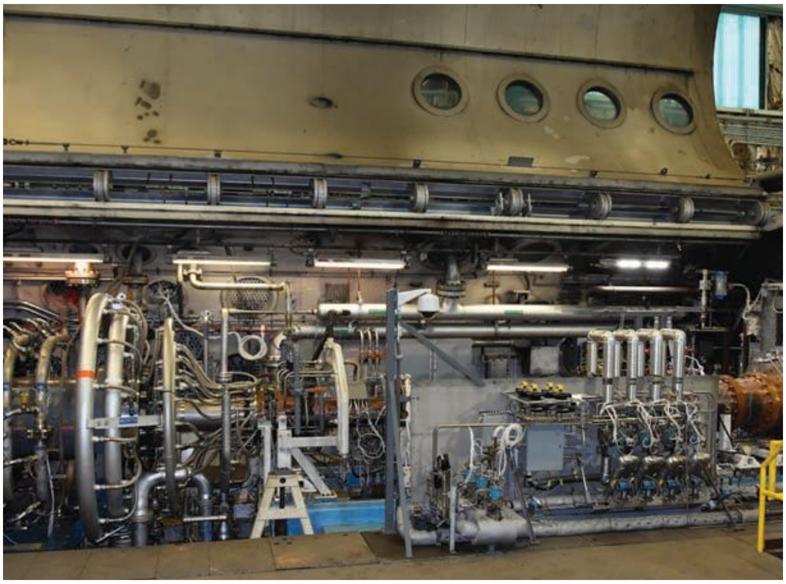
Rolls-Royce of England tested an **M250 turbine engine in a hybrid electric propulsion** system at a test facility in Indianapolis in March. The test matured the hybrid electric system for future aircraft and served as a prototype for larger aircraft. The M250, which typically powers helicopters, demonstrated operation in series hybrid, parallel hybrid and turbo-electric modes.

In June, Rolls-Royce and Aeroflot of Russia celebrated a record for a widebody engine in service. One of **Aeroflot's Trent 700** engines completed 50,000 engine flying hours without requiring an overhaul. The engine first entered service in 2008 and powers an Airbus A330 aircraft.

GE Aviation of Ohio accrued 300 hours of flight time on the **GE9X** engine during a second wave of flight testing that concluded in May on GE's **747 Flying Test Bed** in Victorville, California. In total, GE flight-tested the GE9X for about 500 hours. GE also announced in July that the GE9X set a new Guinness World Records title after reaching 134,300 pounds of thrust (597 kilonewtons) in a November 2017 test at its Peebles, Ohio, test stand.

GE Aviation announced in June at the Paris Air Show several records set by the **18,000-pound thrust (80 kN) Passport engine**. Since beginning operation in December 2018, the Passport-powered **Bombardier Global 7500** set multiple records for a business jet, including a speed record from New York to Los Angeles with flight time of 3 hours, 54 minutes and a top speed of **Mach 0.925** in March. Bombardier, headquartered in Montreal also set a **nonstop distance record** with the Global 7500 of nearly 15,100 kilometers, flown between Singapore and Tucson, Arizona, in March.

At the Paris Air Show, GE Aviation, Rolls-Royce and United Technologies Corp. (parent company of Pratt & Whitney) announced with several airframe suppliers a commitment to continue developing technologies to **aggressively reduce emissions** by 2050. Reductions, as stated in "The Sustainability of Aviation" are "enabled by advances in new architectures, advanced engine thermodynamic efficiencies, electric and hybrid-electric propulsion, digitization, artificial intelligence, materials and manufacturing." The announcement demonstrated the strong commitment of the aviation industry to rapid technology growth for decades to come. ★



Lighting fires that can't be extinguished

BY GREG JOHNSTON, KHALED SALLAM AND ALEX CINTRON

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.

▲ **The Aerodynamic and Propulsion Test Unit** at Arnold Engineering Development Complex in Tennessee, where a scramjet set a record.
U.S. Air Force

In August, the U.S. Air Force announced that a Northrop Grumman-built **air-breathing hypersonic engine** set an Air Force record for thrust. The **supersonic combustion ramjet or scramjet engine** achieved over 13,000 pounds (58,000 newtons) of thrust during nine months of ground testing by the Aerodynamic and Propulsion Test Unit at the Air Force's **Arnold Engineering Development Complex** in Tennessee.

The 5.5-meter-long engine demonstrated an unprecedented and remarkably large increase in mass flow capacity, compared to the service's last major scramjet initiative, the flights of the **X-51**. "A new engine with 10 times the flow of the X-51 would allow for a new class of scramjet vehicles," said Todd Barhorst, an Air Force Research Laboratory aerospace engineer, in an Air Force news article. Barhorst is the lead for the Medium Scale Critical Components Scramjet program.

Engineers were pleased that the engine endured an accumulated half hour of combustion over the course of the test program.

The tests were made possible by a two-year upgrade to the **Aerodynamic and Propulsion Test Unit's** facility.

NASA, in September, completed fabrication of the **Isolator Dynamics Research Laboratory** at Langley Research Center in Virginia, which is capable of Mach 2.5 cold flow.

In June, Purdue University received a $5.9 million contract from AFRL for risk-reduction and design studies for a **Mach-8 quiet wind tunnel** to be constructed at the university.

In July, Space Engine Systems Inc. of Edmonton, Alberta, which aims to build a **single-stage-to-orbit scramjet vehicle**, tested a complete engine at a 4-kilonewtons thrust scale, simulating conditions from takeoff to Mach 5 at an altitude of 98,000 feet. Performance of the connectionless titanium heat exchanger was demonstrated this year by removing 3.9 megawatts for just under 11 milliseconds. **Heat transfer rates were increased by 40%** by injecting nanoparticles in upstream hydrogen, confirming the selection of Boron Carbide nanoparticles for rapid pre-cooling, shockwave control and augmented combustion performance.

In Europe, the **Institute of Space Propulsion at DLR, the German Aerospace Center**, conducted experiments to investigate acoustic flow instabilities and the applicability of transpiration cooling systems in scramjets and the interaction between a wedge/flame holder and coolant secondary flow. The DLR's test facility in Lampoldshausen, can achieve combustion chamber inlet conditions **simulating flight speeds ranging from Mach 5.5 to 8**. In January, the facility was upgraded with optical measurement capabilities; high-speed and pseudo-color background-oriented schlieren. The facility's shock generator positions were explored for shock-boundary layer interactions using gaseous hydrogen as a secondary coolant through different porous wall segments made of sintered stainless steel and carbon fiber reinforced ceramics. The cooling efficiency of the hydrogen was increased by these interactions, while the reflected/impinging shocks and interactions led to coolant ignition. DLR, in May, also focused on acoustically generated instabilities in the combustion chamber flow, nozzle flow and inlet flow, where it was proved that screeching frequencies can cause issues to nozzle and inlet flows, but were mostly swallowed by the combustion chamber.

Turning to Asia, JAXA, the Japan Aerospace Exploration Agency, in April finished building a subscale hypersonic engine and experimental flight vehicle known as **HIMICO, short for High-Mach Integrated Control Experiment**.

India's Defense Research and Development Organization in June conducted a flight test of its **Hypersonic Technology Demonstrator Vehicle**, an unmanned scramjet demonstration aircraft with a short operating capability of about 20 seconds. The trial was carried out from Abdul Kalam Island in the Bay of Bengal. ★

Contributors: *Todd Barhorst, Brandon Chynoweth, Robin Hunt, Jesse Kadosh, Masataka Maita, Sean Smith, Friedolin Strauss and Hideyuki Taguchi*

Advanced manufacturing extends operational boundaries of hybrids

BY TIMOTHY MARQUARDT AND JOSEPH MAJDALANI

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

▲ **Virgin Space Ship Unity** in space with three crew members aboard.
Virgin Galactic

Virgin Galactic in February launched **Virgin Space Ship Unity** into space with a crew of three aboard, 10 weeks after its first trip beyond the 80-kilometer space boundary. Powered by a hybrid motor that provided 320 kilonewtons of thrust for nearly 60 seconds, this spaceship reached **Mach 3.04** and an apogee of nearly 90 km before returning to the Mojave Spaceport in California.

Researchers at Stanford University demonstrated **laser ignition of a hybrid fuel grain** in a lab-scale slab burner. They presented high-speed imaging results in July that identified the underlying ignition mechanism as the entrainment and laser heating of small soot particles formed during fuel pyrolysis or chemical decomposition. A small and lightweight laser diode, combined with a few simple optical elements, provided energy to a specific point on the fuel surface and heated soot particles well beyond the temperature required for fuel pyrolysis. These particles then transferred energy to the vaporized propellant mixture, igniting the motor. Experiments have confirmed that only those fuels that produced soot were compatible with this technique, but the method holds promise for broader applicability. Tests in a single-port motor that aimed the laser at a small target area of a compatible fuel embedded in a larger, non-soot-producing fuel grain demonstrated ignition of the motor at both atmospheric and vacuum exit conditions.

NASA's Jet Propulsion Laboratory in California and Marshall Space Flight Center in Alabama continued to lead technology development for a **Mars Ascent Vehicle** intended to deliver samples from the surface of Mars into orbit. To this end, Whittinghill Aerospace of California carried out **full-scale motor testing of a wax-based fuel with MON-25**, a mixed oxide of nitrogen, in April and July at the Mojave Spaceport. Test motors and oxidizer were conditioned to an assumed Mars operational temperature of minus 20 degrees Celsius. In this study, researchers achieved high-performance, stable burns with durations of 60 seconds. The Space Propulsion Group of California and Montana performed similar but smaller, separate tests in Butte, Montana, in January and April and had the same results. In addition, researchers at Purdue University in August presented findings that they demonstrated the hypergolic ignition and multiple relights of a paraffin-based hybrid motor with various hypergolic solids added to the headend of the **fuel grain containing MON-25**. Tests showed good agreement with previously completed MON-3 testing, with some tests experiencing ignition delays.

The **additive manufacture of advanced hybrid rocket motors** to enhance burn rates and efficiencies continued to grow. This year, the Aerospace Corp. of California produced hollow liquid fuel grains that used 3D-printed features to meter the delivery of liquid fuels such as kerosene. This arrangement combined the capabilities of liquid-engine performance with the safety and simplicity of hybrids. In the first half of the year, Aerospace Corp. flight-tested an advanced hybrid rocket with these new liquid grains and a 54-millimeter rocket motor.

In a separate program, Aerospace Corp. and Penn State continued development of a **hybrid propulsion unit for cubesats**. Collaborators at Penn State demonstrated start, stop and restart capabilities of the unit early in the year before returning it to the Aerospace Corp. for further development. The propulsion unit consists of a 3D-printed solid fuel grain in a combustion chamber integrated into and surrounded by a toroidal oxidizer tank. The chamber/tank component was created with direct metal laser sintering, a form of 3D printing that melts metal powder together with lasers. This technique eases the production of intricate parts that possess the necessary thermal and mechanical properties for use in propulsion systems.★

Contributors: *David Dyrda, Andrew Cortopassi and George Story*

2 supersonic aircraft programs reach testing milestones

BY JONATHAN S. LITT, TIM CONNERS AND JEFFREY D. FLAMM

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.

Boom Supersonic made substantial progress in the design, assembly and testing of its **XB-1 supersonic demonstrator** aircraft. This work culminated in engine ground testing, which concluded in February at the U.S. Air Force Academy in Colorado. The test demonstrated that measured inlet distortion levels were acceptable for XB-1's three **GE J85-CAN-15** engines. This achievement followed wind tunnel testing of the inlet at the Boeing Polysonic Wind Tunnel in St. Louis in late 2018.

The XB-1's 2D hybrid compression inlet model was designed for sustained Mach 2.2 operation and uses modular fore and aft ramps, spill door geometry and a wide-throat bleed slot that was based on Concorde's. An **aft-mounted auxiliary intake** effectively reduces low-speed distortion, although it is not required to meet flow demand. Analysis of test data proved that high throat bleed gives the inlet a modest amount of efficient internal compression and produced test-based pressure recoveries across the operating range that met or exceeded Concorde's published performance. The functional design and analysis of the inlet was completed in nine months, with the model fabrication taking an additional three months. A shortened development phase was made possible by baselining the design from a known successful example, **Concorde's wide-throat slot inlet**; by judicious use of well-understood computational tools and methods along with the ability to upsurge CPU demand as needed using cloud computing; and by restrained parametric surveys that allowed rapid convergence toward a high-performance, though not necessarily optimized, design.

Another noteworthy XB-1 development at Boom this year is the design of the vehicle's **aerodynamically complex secondary flow path** through the extensive use of computational tools. This involved modeling the throat bleed management, engine bay cooling flow, pressure relief systems, integrated ejector nozzle and J85 variable nozzle geometry. Ejector nozzle performance was characterized using **high-fidelity computational fluid dynamic models** of the fully coupled secondary flow path. This effort improved aero-model fidelity and reduced uncertainty of the overall vehicle mission performance. Along with axisymmetric inlet concepts, the test-verified 2D inlet geometry and architecture are supporting conceptual design studies for Overture, Boom's commercial supersonic airliner.

In preparation for the **X-59 Quiet Supersonic Technology** critical design review, which occurred in September, engineers from Lockheed Martin, General Electric and NASA completed NASA's low-boom flight demonstrator inlet dynamic distortion test entry at the **8-by-6-foot Supersonic Wind Tunnel** at NASA's Glenn Research Center in Cleveland in May. The test verified the acceptability of the unsteady inlet distortion characteristics. The 9.5% scale model was tested at Mach numbers from 0.3 to 1.55. A mass flow plug was used to vary inlet mass flow. Instrumentation included an 80-probe rake at the aerodynamic interface plane: 40 pitot pressure probes and 40 high-response Kulite probes in side-by-side arrangement. ★

▼ The X-59 Quiet Supersonic Technology 9.5% scale model was tested at Mach numbers from 0.3 to 1.55 in the 8-by-6-foot Supersonic Wind Tunnel at NASA's Glenn Research Center.
NASA

Commercial Crew, engine tests mark an active year

BY DAVID J. COOTE AND VINEET AHUJA

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

▲ **The Space Launch** System's core stage pathfinder is positioned in the B-2 Test Stand at NASA's Stennis Space Center in Mississippi. Crews practice handling skills with a pathfinder before working with the real core stage.
NASA

Significant progress was made this year in NASA's **Commercial Crew program**. In March, SpaceX launched to the International Space Station an uncrewed Dragon capsule on a Falcon 9 rocket and then recovered the rocket. The Falcon 9 first stage that will launch the first crewed mission completed static hot-fire acceptance testing in April. In other Commercial Crew activities, **Boeing's CST-100 Starliner** completed key propulsion system mission static testing in May, simulating on-orbit maneuvering and high-and-low altitude abort. Blue Origin flew the New Shepard suborbital vehicle in May in preparation for its first human flight. In May, Blue Origin unveiled its BE-7, a highly efficient, deep-throttling engine with restart capability that can power in-space systems.

In other commercial activities, United Launch Alliance's next-generation launcher, **Vulcan Centaur**, powered by BE-4 engines in the first stage and RL-10 engines in the upper stage, completed its final design review in May. In January, Blue Origin initiated the process to build the **BE-4 engines** that will also be used to power its New Glenn rocket. In August, Sierra Nevada Corp. announced it would use the Vulcan for its **Dream Chaser** spacecraft, which completed its final design review in December 2018.

In August, NASA's **Space Launch System core stage pathfinder** was fit-checked in the B2 test stand at NASA's Stennis Space Center in Mississippi in preparation for installation and hot-fire testing of the SLS Exploration Mission-1 core stage in May 2020. In February, NASA and Aerojet Rocketdyne resumed hot-fire testing of the **RS-25 engines** at Stennis. Aerojet Rocketdyne also delivered eight 490 newtons (110 pounds) of thrust **R-4D** auxiliary engines to be used on the **European Service Module** supporting the Orion spacecraft for the **Artemis-2** mission.

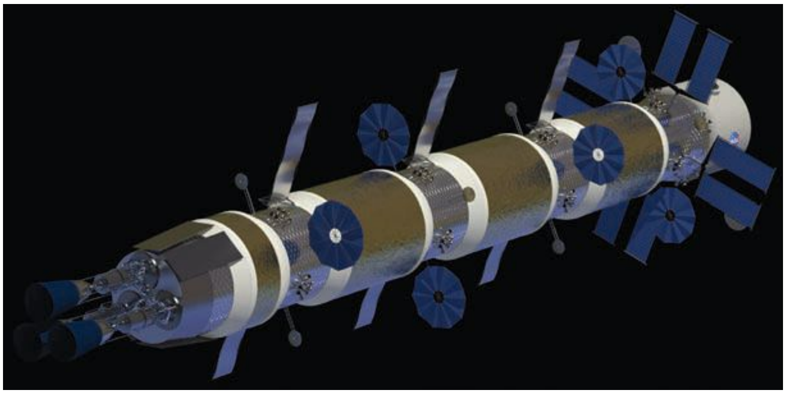
In Europe, Ariane Group qualified its **cryogenic propulsion systems** for the Ariane 6; the upper stage Vinci engine passed its final qualification review in June, and the lower stage Vulcain 2.1 engine completed qualification testing in July, accumulating a total operation burn time of 13,800 seconds. **Prometheus**, a European Space Agency future launcher preparatory development effort to create a reusable LOX/methane engine, completed its subsystem's manufacturing readiness reviews in 2019, and two demonstrator engines are planned for hot-fire testing in 2020. JAXA, the Japan Aerospace Exploration Agency, continued the development of the first-stage **LE-9** engine and the second-stage **LE-5B3** engine for its first H3 flight in 2020. The LE-9 engine completed engineering model hot-fire testing in October and was to start qualification testing in December at Tanegashima Space Center. Testing of the Battleship H3 first stage (two LE-9s), initiated in December 2018, was to finish in December at the Tashiro Test Complex. The LE-5B3 finished qualification testing in February at the Kakuda Space Center and Tashiro.

In small thruster news, in January, Aerojet Rocketdyne's **monopropellant hydrazine propulsion system** powered the **New Horizons** spacecraft on the most distant solar system flyby as it passed within 3,500 kilometers of Kuiper Belt object **Ultima Thule**, 3½ years after its Pluto flyby. In June, as part of a joint effort among Aerojet Rocketdyne, Ball Aerospace, NASA and the U.S. Air Force Research Laboratory, the **Green Propellant Infusion Mission** was launched. It's a 13-month demonstration of the AFRL's revolutionary "green" propellant, AF-M315E.

In additive manufacturing activities, a full-scale, **3D-printed high-pressure liquid oxygen/kerosene rocket engine combustion chamber** incorporating additive copper alloy GRCop-84 completed testing in February at NASA's Marshall Space Flight Center in Alabama for Virgin Orbit, delivering 8,900 newtons (2,000 pounds) of thrust in 24 60-second test firings. In April, Aerojet Rocketdyne also completed initial testing of its next-generation **RL10C-X** engine that uses a 3D-printed injector and thrust chamber.

In April, the University of Southern California's Rocket Propulsion Laboratory designed, built and launched a rocket that passed the Karman line, believed to be a first for a student team. ★

Contributors: *Colin Cowles, Steven Baggette, Christoph Kirchberger, Scott Miller, Koichi Okita, Timothee Pourpoint, Dieter Preclik and Chandrashekhar Sonwane*



Nuclear propulsion planning focuses on modular, sustainable designs

BY BRYAN PALASZEWSKI

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.

▲ An artist's rendering shows a modular and sustainable nuclear thermal propulsion space vehicle for crewed missions to Mars. Hydrogen fuel would be heated by three nuclear fission reactors and exhausted through converging-diverging nozzles to produce thrust.
Aerojet Rocketdyne

Since 2016, NASA has been exploring low-enriched uranium, LEU, reactors for nuclear thermal propulsion or NTP. The **LEU NTP project**, led by NASA, is aimed at developing a demonstrator to fly before 2030 as a test for crewed missions to Mars. Significant conceptional design evaluations and work were completed toward LEU NTP in 2019.

In February, the LEU NTP project received additional funding and initiated several studies with industry and U.S. Energy Department labs.

In May, Aerojet Rocketdyne refined its **predicted performance modeling** of an LEU NTP engine.

In July, researchers at NASA's Marshall Space Flight Center in Alabama revisited demonstrator vehicle concepts through various design cycles.

In August, retired nuclear engineer David Black published a study concluding that **low-enriched uranium reactors**, though higher in mass than a highly enriched uranium reactor, can be designed to meet the mission, lifetime and operability requirements of NTP missions while simultaneously offering less stringent safety, security and proliferation concerns.

Also in August, the Energy Department's Sandia National Laboratories, Oak Ridge National Laboratory and Idaho National Laboratory worked with Marshall and BWX Technologies of Virginia to develop a path forward for **LEU NTP fuel selection and reactor design**.

In other advanced propulsion areas, NASA's Innovative Advanced Concepts office in April conducted a Phase II midterm review for a proposal awarded in 2018 to California State University-Fullerton to continue its experimental efforts examining **the Mach effect**, a theoretical form of gravitational propulsion that does not expel mass and only uses electrical power. CSU-Fullerton has been developing and testing Mach effect devices for 25 years as well as refining the theory of operation. Experiments in Germany, Canada and Italy and by multiple independent researchers in the U.S. are heavily focused on thrust balance calibration, experimental procedure, signal amplification and corrections to the theory. The forces generated from these devices are generally less than 10 micronewtons, but the true nature and source of the signals remains inconclusive. If the theory is found to be legitimate, Mach effect research could pave the way for **new propulsion physics** and have applications well beyond space systems.

Researchers from Quantum Fields LLC in Illinois; the Institute for Advanced Studies in Texas; and the Center for Astrophysics, Space Physics and Engineering Research at Baylor University in Texas published new results in August on producing and accessing the negative quantum vacuum energy densities theoretically required by general relativity to produce novel propulsion schemes such as **warp drives and worm holes**. This work noted the startling fact that the theoretical quantum inequality restrictions needed to generate such energies have not been experimentally tested. The researchers analyzed the various technical schemes known to produce "squeezed vacuum states" with the technique called a "squeezed light" and discovered that the restrictions were violated in the evaluated published quantum optics squeezed light experiments (represented by 25 years of published data). The **Casimir effect** (with negative vacuum energy density in the space between the two Casimir cavity walls) is also expected to demonstrate experimental violation of quantum inequality, but this experiment has yet to be demonstrated in the lab because of numerous technical challenges. The consequence of the experimental violations of quantum inequality was that nature does not impose any truly significant constraint on technologically producing and accessing negative vacuum energy density; this result implied that there should be no roadblock to artificially producing a warp drive or a traversable wormhole to achieve faster-than-light propulsion for interstellar flight.

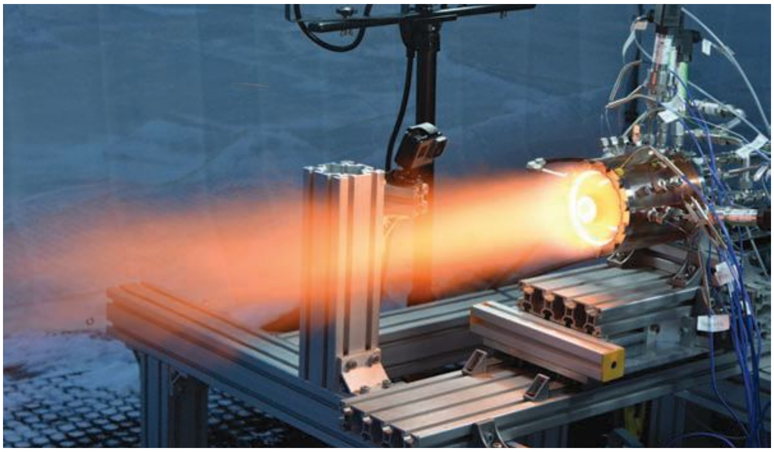
In August, Stan Borowski presented a summary of recent design studies in both nuclear thermal propulsion and in-situ resource utilization that could lead to viable experiments blending the two technologies. This work will be critical for planning and modeling missions using NTP. Borowski retired in December 2018 from NASA's Glenn Research Center after a 30-year career. ★

Contributors: *Eric Davis and Greg Meholic*

Advances in science and technology of pressure gain combustion

BY AJAY AGRAWAL AND DON FERGUSON

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.



▲ **A rotating detonation engine** was tested at Nagoya University in Japan in preparation for a sounding rocket experiment planned for 2020.

Nagoya University

For propulsion and power-generation systems, **detonation-based pressure-gain combustion** has the potential to deliver higher fuel efficiency at reduced weight and footprint. This makes PGC attractive for terrestrial systems, as well as aerospace applications such as rockets and hypersonics. Recent investments have enabled quantitative flow and combustion diagnostics and improved the technology readiness level by transitioning laboratory concepts toward practice. Government, industry and academic institutions around the globe this year continued to advance PGC to a new and higher technical level.

The U.S. Air Force, Navy, Department of Energy and NASA continued to support several PGC research efforts. In June, the Air Force Research Laboratory and Innovative Scientific Solutions Inc. conducted a ground demonstration of **a rotating detonation engine, or RDE, capable of propelling a Long-EZ aircraft**. This effort demonstrated adequate thrust for takeoff and cruise operation, and acoustic measurements confirmed a safe noise level for ground operations.

The Department of Energy's National Energy Technology Laboratory funded RDE development efforts by Aerojet Rocketdyne with teammates from Purdue University, University of Michigan, University of Alabama, University of Central Florida and Southwest Research Institute. In May, the campaign conducted **hot-fire testing of a 30-centimeter diameter natural gas and air RDE** at Purdue's Zucrow Labs. Using multiple hardware configurations, the team demonstrated detonation combustion with a low loss injector and an exhaust diffuser designed to condition the exit flow for a downstream turbine.

NASA researchers continued in-house numerical investigation and optimization efforts in resonant pulse combustion and RDE systems for application to gas turbine engines. Additionally, under an internal Center Innovation Fund, a rotating detonation rocket engine nozzle optimization study and high-level rocket system benefits model development were initiated. In May, NASA solicited development proposals under Phase I Rocket Engine and Research, Development, Demonstration, and Infusion Early-Stage Innovations grants programs.

In August, researchers at Purdue University reported development of **an axial and outflow radial turbines suitable for small core RDEs**. In an effort to assess the performance of the turbine-combustor interactions, an optically accessible test rig was developed in cooperation with Spectral Energies.

In February, University of Michigan researchers **identified and quantified regions of parasitic and commensal secondary combustion** that affect the detonation wave in an RDE and identified the presence of secondary waves. Secondary combustion and secondary waves couple together, ultimately changing the stability and structure of the primary detonation wave.

In March, a team of researchers at the University of Alabama used time-resolved particle image velocimetry to measure the exhaust flow of an RDE operated on methane and oxygen-enriched air mixtures and demonstrated that the circumferential flow oscillations decreased by operating the RDE at high pressures, and a downstream diffuser further homogenized the flow for turbine applications. Activities at the Naval Postgraduate School from April through June focused on RDE parametric studies of combustor inlet area ratios, channel width and back-pressurization conditions to determine pressure-gain performance. This was done through the application of **equivalent available pressure** which is an important parameter in evaluating the performance of a PGC device.

In Japan, Nagoya University, Keio University, Institute of Space and Astronautical Science of Japan Aerospace Exploration Agency, and Muroran Institute of Technology **fabricated the preflight model of a detonation engine system** toward a sounding-rocket spaceflight test scheduled for August 2020.

At Tsinghua University in Beijing, the **effects of a perforated wall on the hydrogen/air rotating detonation** were studied emphasizing analysis of acoustics and propagation stabilities. Experiments were also performed on kerosene/oxygen-enriched air rotating detonation. Using an Eulerian-Lagrangian two-way coupling model, a 2D simulation of two-phase kerosene-air rotating detonation was conducted using high-order numerical methods. ★

Expanding ignition and combustion limits and alternative fuels for the future

BY TIMOTHY OMBRELLO AND CLARESTA DENNIS

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.

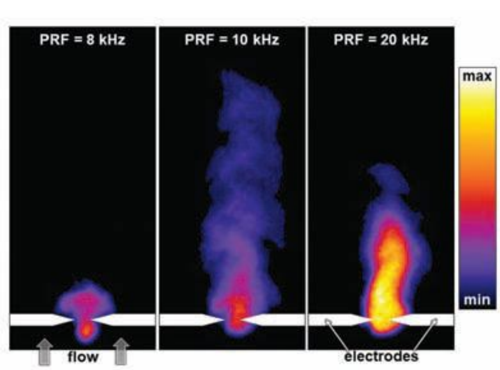
Multiple milestones were achieved this year that demonstrated the unique advantages of **repetitive pulsed discharges for ignition** in reacting flows relevant to a variety of engines.

The milestones were achieved through collaboration among the U.S. Air Force Research Laboratory in Ohio, the Technion-Israel Institute of Technology, Oregon State University, Texas A&M University, University of Central Florida and University of Dayton.

In January, **infrared imaging thermometry** showed that the synergy between pulses at frequencies greater than or equal to 10 kilohertz produced elevated temperature ignition kernels, which explained the higher ignition probabilities and more rapid kernel growth rates observed in previous years' efforts. Complementing the temperature measurements, 50-kHz planar laser-induced fluorescence measurements, in April, confirmed that sustained elevated concentrations of hydroxyl radicals are present in developing ignition kernels for greater than or equal to10 kHz pulsation rates.

In July, optical emission spectroscopy measurements revealed that pulsation frequencies of 250 kHz nearly doubled the translational temperature over single pulse temperatures. The results thus far have shown that **high-frequency repetitive pulsing** allows enhanced and optimized ignition in reacting flows.

In a quest to decrease emissions for commercial aircraft engines, a six-month computational effort funded by NASA's Glenn Research Center in Ohio ended in February after developing the initial design of a **novel injection system**, called Lean Fully Premixed. This injection method achieves **fully premixed combustion** with the key advantages of minimizing NOx (nitrogen oxides) and eliminating soot and fuel spray. Preliminary results with numerical simulations are encouraging, and the design must be numerically optimized and experimentally tested. The LFP injection system offers a route toward the application of a premixed combustion mode for significant advancement of aircraft propulsion. Results were published at the ASME Turbo Expo 2019 and the AIAA Propulsion and Energy Forum 2019.



▶ **Hydroxyl radical planar** laser-induced fluorescence images of ignition at 100 microseconds after the last spark discharge in 10-pulse bursts at 8, 10 and 20 kilohertz pulse repetition frequencies applied in a premixed methane-air flow. Elevated hydroxyl radical concentrations for pulse repetition frequency greater than or equal to 10 kHz lead to higher ignition probabilities and more rapid kernel development to enhance ignition across a broad range of engine combustors.

U.S. Air Force

Following the theme of lean combustor operation, an on-going project funded by AFRL studied **lean blowout**, or LBO, and intrinsically flame stabilization. Transient sequences of a laboratory-scale premixed flame were undertaken and identified the role of the swirling flow inner recirculation zone during the LBO. Premixed simulations were performed to resolve the flame-front thickness at nearly the Kolmogorov scales throughout the domain. The overall dynamics and simulation results favorably compared with experiments.

Shifting to **sustainable aviation fuels**, or SAF, work this year under the multiagency **National Jet Fuels Combustion Program**, a European collaborative program, and a Navy program developed a two-tiered prescreening methodology to predict and measure properties and, in turn, predict the effect of these properties on critical high volume and cost approval tests. ASTM D4054, the process for SAF approval is complex. The proposed prescreening methodologies do not replace the established ASTM process, but can provide a producer with increased confidence of approval and perhaps accelerate the process. The United Nations International Civil Aviation Organization identifies the market adoption of SAFs as the major opportunity to mitigate the environmental impact of aviation transportation; hence, there is market interest and importance to these new developments.

In support of the SAF prescreening proposal, researchers at the University of Dayton, Purdue University and the German Aerospace Center, DLR, in September developed **software to read gas chromatograph results** to predict critical fuel properties while requiring only microliters of volume, and researchers at Stanford University were planning to apply midinfrared absorption capabilities to predict properties; manuscripts have been submitted for publication describing the new process. A Commercial Aviation Alternative Fuels Initiative technical guidance document (www.caafi.org) posted in September summarized some of these results. Collectively, these prescreening results and methodologies significantly lower the barrier for early SAF evaluations and offer the opportunity to expedite the approval process of novel SAFs. ★

Contributors: *Campbell Carter, Med Colket, Stephen Hammack, Ron Hanson, Joshua Heyne, Gozdem Kilaz, Joseph Lefkowitz, Patrick LeClercq, Paul Palies and Bastian Rauch*

◀ **Northrop Grumman** provided a modified Peacekeeper solid rocket booster and the abort and attitude control motors for the launch of the Orion capsule, seen here just after liftoff for an in-flight test of the launch abort system. Aerojet Rocketdyne built the jettison motor.
Northrop Grumman

Solid rocket motor waves from around the world

BY ORIE CECIL AND JOSEPH MAJDALANI

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

Aerojet Rocketdyne expanded this year with **two new solid rocket motor facilities**. In April, the company began construction on a 17,000-square-foot (5,100 square meter) engineering, manufacturing and development complex for large solid rocket motors in Camden, Arkansas. The company opened a 136,000-square-foot (41,000 square meter) advanced manufacturing facility in June in Huntsville, Alabama.

Beyond new buildings, Aerojet Rocketdyne also achieved a hardware milestone in June when it delivered the jettison motor for Lockheed Martin's Orion spacecraft. The **jettison motor** is responsible for separating Orion's launch abort system from the crew module after a launch or after the crew module has been detached from the main vehicle and reoriented in the case of a launch failure.

Northrop Grumman also played its part in the ongoing development of the **Orion capsule**. In July, when Orion underwent a test of both the capsule and launch abort system, Northrop Grumman provided a modified Peacekeeper booster to lift the capsule and launch abort system, which exposed both systems to atmospheric flight conditions. In addition to the booster, Northrop Grumman provided the abort and attitude control motors.

Apart from its role in the development and testing of the **Orion launch abort system**, Northrop Grumman conducted several tests of other solid rockets. In April, the company conducted the second ground test of the newly developed 63-inch-diameter (160 centimeter) Graphite Epoxy Motor. Known as **GEM 63**, it is a strap-on solid booster motor that will provide extra power to United Launch Alliance's Atlas V. Additionally, in May, Northrop Grumman tested the first stage of its new OmegA rocket in Promontory, Utah. The motor fired for 122 seconds, producing more than 2 million pounds (8.9 million newtons) of thrust.

The European Space Agency, French National Center for Space Studies and Europropulsion collaborated on a test for the first qualification model of the **P120C solid rocket motor** in January. This stands as the second test of the P120C; the first was in July 2018. ArianeGroup and Avio co-developed the P120C in support of the Ariane 6 and Vega-C rockets. It is housed in a monolithic carbon fiber case, making it the largest such rocket in the world.

China's **Smart Dragon-1 rocket** was launched for the first time in August. China Rocket Co. developed Smart Dragon-1, which is designed to deploy small commercial satellites (about 200 kilograms) into orbit using four solid-propellant stages. Also faring from China, iSpace in July became the first private Chinese company to launch a payload into orbit. The payload consisted of several small satellites and was propelled into space on board the Hyperbola-1, which was comprised of four stages, the first three using solid propellants. ★

Contributors: *Clyde Carr, Michel Berdoyes and Scott McHenry*

Progress made toward hydrogen-powered aircraft and biofuels

BY BHUPENDRA KHANDELWAL AND KATHARINE COGGESHALL

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.

Globally, the decrease in fossil fuel reserves and the advent of a climate emergency are pushing society toward different energy sources for propulsion. Renewable power sources may always lack sufficient energy density for some aerospace applications, and therefore additional options need to be explored.

Compressed or **liquified hydrogen** has high specific energy and energy density, making it a good candidate for powering gas turbines in aircraft. However, due to emissions and onboard storage challenges no more study has explored the use of hydrogen as an aviation fuel since the multinational CRYOPLANE Project of the 1990s and early 2000s.

This year saw a renewal of interest in hydrogen as a potential source of propulsive power for aircraft. In a variety of conference presentations and journal papers between June and September, researchers from the University of Sheffield and Cranfield University in the United Kingdom and FH Aachen University of Applied Sciences in Germany proposed **new micromix-based combustor** concepts in which thousands of small flames would maintain combustion. Such designs would produce limited NOx (nitrogen oxide) emissions from the burning of hydrogen with incoming air. These combustors have been proposed to offer lower NOx emissions and good flame stability limits. If successful, these combustors could pave the way for future hydrogen-powered aircraft.

On another front, researchers at Los Alamos National Laboratory identified **ideal algal strains** for producing cost-effective, refinery-compatible diesel and jet fuel precursors.

Biologist Christina Steadman of LANL designed a new suite of flow cytometry techniques and described them in a November paper in the journal Algal Research. These methods fast-track the process of identifying ideal strain candidates for **genetic enhancement**. Steadman can track algal physiology and function within a given strain.

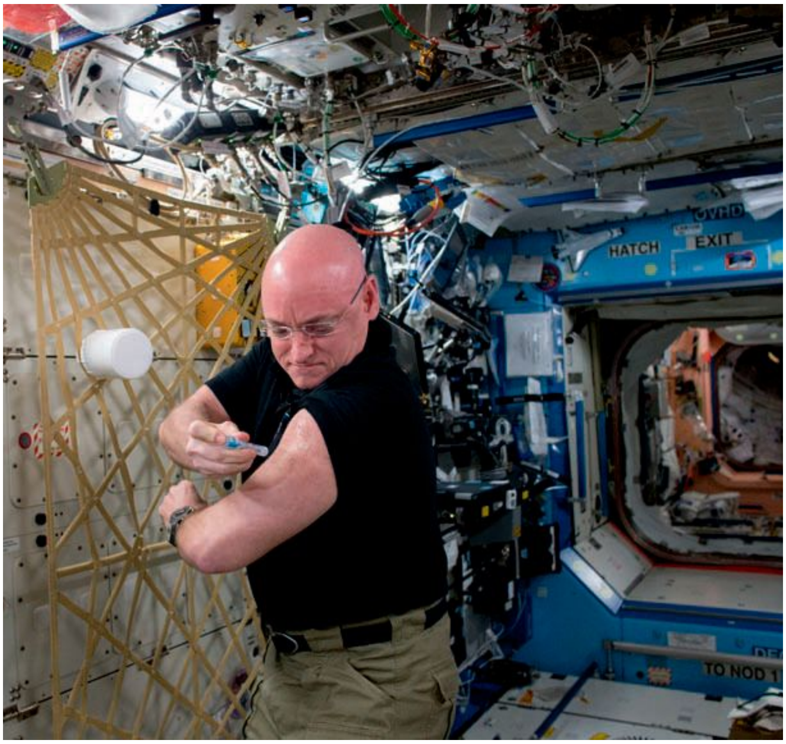
Beyond the identification of strains well-suited for bioengineering, Steadman's techniques also aid in evaluating how algae strains react after bioengineering takes place. Complicated metabolic interactions cannot always be predicted.

Also, Amanda Barry, a LANL biologist and program manager, furthered her groundbreaking 2018 research by identifying additional algaes that have the **ability to break down raw plant biomass**, revealing this characteristic to be more common across algae genera than previously thought.

Barry's 2018 research on Auxenochlorella protothecoides, described in the September 2018 issue of Algal Research, established the first report on direct degradation and utilization of raw plant hemicellulose by a freshwater alga. She showed that the algae can grow, both phototrophically and heterotrophically, by feeding on dried and chopped switchgrass (**common lawn residue**).

Feeding algae with lawn clippings could help make algal biomass production economical, given that lawn clippings are inexpensive or free. The costs of producing biomass from algae compared to the current cost of fossil fuels has been the limiting factor for **viable biofuel competition**. Both Steadman's bioengineering approach and Barry's all-natural approach promise increased algae biomass and lipid production, which are needed to produce diesel and jet-fuel precursors, at a reduced cost. ★

▼ **The Los Alamos** National Laboratory's pond simulator photobioreactor mimics outdoor conditions in algae cultivation, enabling rapid-paced energy security research.
Los Alamos National Laboratory



▲ **Astronaut Scott Kelly** self-administers a flu vaccine on the International Space Station as part of NASA's Twins Study.
NASA

Kelly twins' year-in-space study yields data

BY JONATHAN G. METTS

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

In April, the journal Science published multidisciplinary results of "The NASA Twins Study: A multidimensional analysis of a year-long human spaceflight." This broad suite of bioastronautics research focused on a pair of identical twins, both now retired astronauts, **Scott and Mark Kelly**. For the 27 months of study, numerous samples and metrics were voluntarily collected from the brothers before, during and after Scott's 340-day mission aboard the **International Space Station**. The participation of both twins allowed Mark to become a genetically identical baseline against which to compare the spaceflight-induced changes that Scott experienced throughout his year in space.

The study examined epigenetic changes, which are the body's reaction to an environment through selective expression of genes. Post-landing samples helped researchers learn that while living in space does affect gene expression in myriad ways, most of those changes reverse within a few months of returning to Earth. Conversely, some **epigenetic consequences of long-duration spaceflight** appear to be permanent. Identifying which genes are most affected, and when those expressions onset and stabilize, may lead to personalized treatment, such as gene therapy, to prevent or reverse adverse effects.

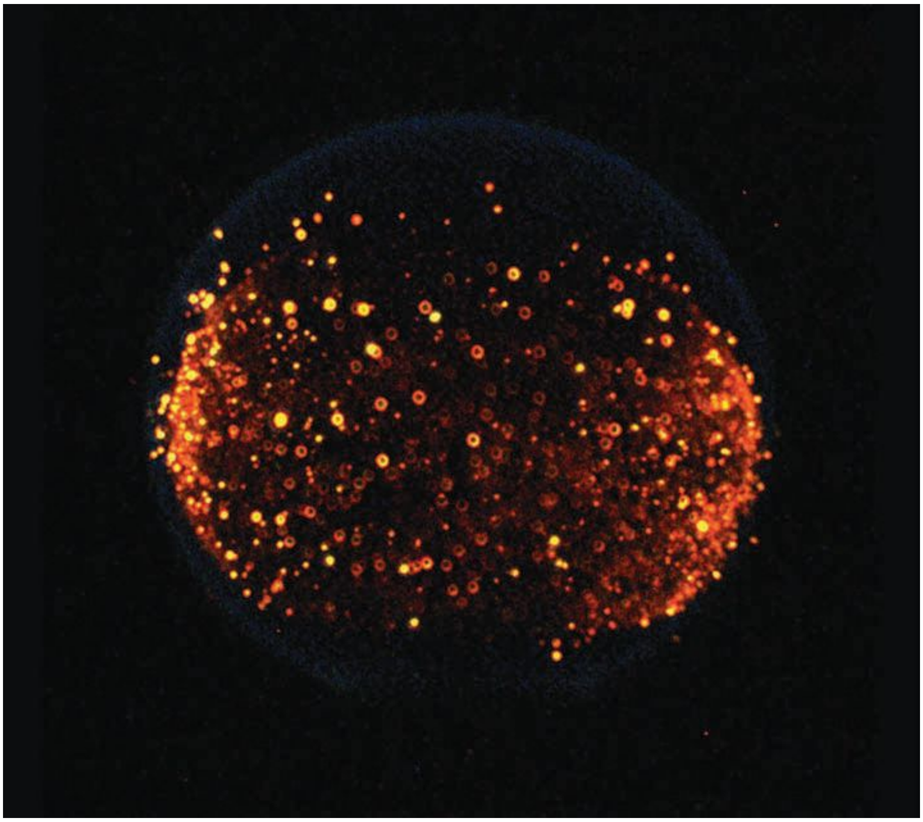
Immunity has long been a concern for astronauts, not least because microbes reproduce differently in microgravity. Researchers are also learning more about the **human immune response** in space; for example, the twins study found that a flu vaccine can be administered and effectively provide immunity in space. This encouraging result is offset by findings that Scott Kelly's immune response and inflammation were negatively affected by the stresses of landing and reintroduction of Earth's environment after long-term adaptation to spaceflight.

Telomeres are the critical end sections of our chromosomes, thought to be related to aging and other biological processes. Scott Kelly's white blood cell telomeres unexpectedly lengthened in space, but were then shorter than their original length upon his landing and eventually returned to baseline length after a few months on the ground. These results suggest that long-term **spaceflight may affect aging** and other aspects of genetic stability. NASA is planning follow-up studies to further confirm and characterize these previously unknown effects.

Researchers also found that **significant cognitive degradation** develops over a year in orbit and then remains after months of adaptation back to conditions on Earth. Metrics that don't seem to recover quickly, if at all, are particularly concerning to NASA mission planners, who need to keep a flight crew healthy and savvy for Mars surface operations after enduring several months in deep-space transit.

In October, NASA sought industry feedback on plans to eventually outsource its **new spacesuit for lunar and planetary exploration**, named xEMU. The agency is committing to build and test the first suits of this new design, already many years into development. These initial, NASA-produced suits will be flown on ISS in 2023 and are scheduled to be worn when humans once again walk on the moon as early as 2024, as part of the **Artemis 3** mission. Looking beyond, NASA plans to hand over subsequent suit production to industry partners, and its solicitation addresses commercialization of suit upgrades, tools, vehicle interfaces and spacewalk opportunities for non-NASA customers.

NASA astronauts Jessica Meir and Christina Koch performed the **first all-female spacewalk** in October. They installed a new power charging unit outside the ISS. NASA had planned an all-female spacewalk for March, but those plans were deferred for lack of a second medium-size torso piece of the American spacesuit, known as the ISS Extravehicular Mobility Unit. ★



▲ **A flame ignited in the** Combustion Integrated Rack on the International Space Station to investigate the amount of soot that is produced. The soot clusters glow yellow when hot. These clusters grow larger in microgravity than on Earth because the soot remains within the flame longer.
NASA

Microgravity research advances physical, biological and material sciences

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.

Astronauts on the International Space Station carried out about **300 microgravity experiments** this year. The commercial and research experiments included those in physical and life sciences and advanced manufacturing.

Scientists from NASA's Glenn Research Center in Ohio oversaw the flame design experiment, which aims to optimize oxygen-enriched combustion by examining the production of soot. Flame design is part of the **Advanced Combustion via Microgravity Experiments**. The flame design experiment was conducted in the **Combustion Integrated Rack, or CIR**, which provides an isolated environment to conduct combustion-related experiments. A flame in reduced gravity tends to be spherical. While on Earth, hot gases from the flame rise, while the cooler dense gas is pulled down by gravity.

Astronauts conducted the flame design experiment from March to October. Experimenters burned fuel with inert gas to study the quantity of soot produced under different flame conditions. The soot clusters produced by a flame glow yellow when hot and they grow larger in microgravity because the soot remains within the flame longer. The research is aimed at **reducing pollutant emission** in practical terrestrial combustion and spacecraft fire prevention research.

Microgravity effects on humans are of concern for long-term residence on the ISS and potential deep space missions. Scientists at the University of Washington School of Pharmacy and UW Medicine, with collaborators, designed an experiment to study **microgravity effects on human kidney health**, specifically on segments of renal tubules (the renal tubule receives plasma filtrate and processes it into the urine). The researchers launched the **Kidney-on-a-Chip Space Project** to the ISS in May. The 24 credit-card-size chips have fluid microchambers that are lined with human-derived kidney cells for examining two segments of the renal tubule with different aspects of filtrate absorption. Experimenters will analyze the chips upon their return to Earth.

March marked the third anniversary of additive manufacturing on the ISS, where machinery has produced 115 tools. Additionally, this year saw the launch of an innovative 3D printer by Techshot Inc., an ISS commercial facility partner, and nScrypt, a manufacturer of industrial 3D bioprinters and electronics printers, to **manufacture human tissue in microgravity**. In August, astronauts began operating the **3D BioFabrication Facility**, which "uses adult human cells (such as stem or pluripotent cells) and adult tissue-derived proteins as its bioink to create viable tissue," according to a Techshot news release. Manufacturing of soft human tissue on Earth is hampered due to soft tissue collapse in gravity. Experimenters aim to use the 3D BioFabrication Facility to print soft tissue and strengthen cell-culturing systems before sending them back to Earth to potentially create patient-specific replacement tissues.

This year also marked the 15th flight opportunity for the **Students Spaceflight Experiment Program**. Each year, this program gives hundreds of students a chance to design experiments to fly aboard the ISS. This year, 3,683 students submitted proposals and 41 experiments flew to the ISS. A total of 23,117 students from fifth grade through college were involved. ★

A camera aboard the MarCO-B cubesat snapped this image of Mars as it flew by the red planet in November 2018 after completing its telemetry relay contribution to NASA's Mars InSight mission. In February, NASA announced that both MarCO satellites had gone silent.
NASA/JPL-Caltech

Small satellites deliver science, communications, commercial missions

BY MARTIN LINDSEY

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.

Small satellites arrived big time on the stages of global commerce and interplanetary research in 2019, and many anticipated regulatory changes promise to further hasten the revolution.

Several companies expanded their commercial offerings focused on information derived from **frequent Earth observations** in many phenomenology. Although the first synthetic aperture radar small satellite demonstration missions occurred in previous years, this year saw the first realization of their commercial potential. The 70-kilogram **ICEYE X3** launched in May, and X4 and X5 launched in July, providing 1-to-10-meter resolution X-band SAR imagery for government and commercial customers. San Francisco-based Capella Space is also poised to provide **ubiquitous SAR imagery** to the commercial market. With its first demonstration launch in December 2018 and first commercial launch scheduled before the end of 2019, Capella had raised $50 million as of June toward realizing its mission of flying 36 satellites with a **resolution of 50 centimeters and one-hour revisit rates**. San Francisco-based companies Planet and Spire and Virginia-based companies Black Sky and HawkEye360 and several other commercial ventures expanded their on-orbit constellations and firmly established the commercial market for imagery and business intelligence products.

Global broadband internet took two large steps forward in 2019. In February, OneWeb launched six of its prototype small satellites on a Soyuz-ST-B Fregat mission. The company has a planned constellation of **648 microsatellites of 125 kg each**. The first six satellites were dedicated to connecting remote schools throughout the world. OneWeb also announced in September that it would be the first company to provide **300 gigabytes-per-second communications capacity to Arctic regions** above 60-degrees north latitude by late 2020. Although the communications satellites would not technically be small satellites at 227 kg each, OneWeb announced its Arctic plans after SpaceX began launching its global internet constellation, **Starlink**, in May with 60 satellites of a planned constellation in the thousands.

Small satellites continued expanding their interplanetary research contributions as well. The **Mars Cube One, or MarCO-A and -B satellites**, NASA's first interplanetary cubesats, completed their mission in January providing near real-time telemetry relay of Mars **InSight's entry, descent and landing**. MarCO-B, carrying a commercial camera with a fish-eye lens, returned a stunning "farewell" image of Mars after completing its primary mission. The first commercial lunar lander mission, **Beresheet** at 150 kg, made it to lunar orbit in April but suffered an engine failure on descent to the lunar surface and crashed upon its attempted landing in Mare Serenitatis.

This past year also saw **quicker launch cadence** and a promising increase of launch opportunities for small satellites. As of October, Rocket Lab had launched five small-satellite-dedicated missions in 2019, deploying 15 small satellites. Virgin Galactic's Launcher One was slated for its initial test flight before the end of 2019. ★

Contributors: *Scott Palo, Bryan Rogler and Michael Swartout*

Portals to lunar exploration take shape

BY BARBARA IMHOF AND 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.

▲ **A design for the** "Moon Village," a concept for the first full-time human habitat on the moon.
Skidmore, Owings & Merrill LLP

Lunar Gateway development was a nexus of space-architecture activity this year. In the United States, five contractors constructed **full-scale habitat ground-test models** for evaluation at several locations as part of the **Next Space Technologies for Exploration Partnerships program, or NextSTEP**. In Europe, consortiums of space systems companies advanced designs for living in deep space.

Lockheed Martin was the first to open its habitat model for evaluation, in February and March, at NASA's Kennedy Space Center in Florida. Lockheed based its concept on a **repurposed "multipurpose logistics module"** from the space shuttle era. Modularity to support a diversity of missions was a top priority.

Northrop Grumman Innovation Systems was next, in April and May, at NASA's Johnson Space Center in Texas. Northrop derived its concept from its **Cygnus cargo spacecraft**, which is already in production. The company has made progress to evolve Cygnus into a habitable spacecraft, including the design and placement of docking ports and radiators. It remains compact enough to fit within the existing payload fairings of commercial launch vehicles.

Boeing followed in June at NASA's Marshall Space Flight Center in Alabama. Its press release noted that the concept "builds on the company's experience from designing, building and operating the [International Space Station] for more than 20 years." It comprised two modules: a **dedicated habitat and an airlock that could provide additional living and working volume**. The modules would ride to lunar orbit aboard NASA's new Space Launch System under the **Artemis program**.

Sierra Nevada Corp. opened its model in July, also at Johnson. It adopted inflatable technology originally pioneered by NASA and Lockheed Martin, subsequently licensed by Bigelow Aerospace, and for which the patent has now expired. Sierra Nevada dubbed its module the **Large Inflatable Fabric Environment**. Fully inflated, it measures 8 meters (27 feet) in diameter and length, providing about 300 m^3 of pressurized volume, divided into three decks parallel to the cylinder axis. Despite its large deployed volume, it could pack into a 5 m payload fairing on a commercial rocket.

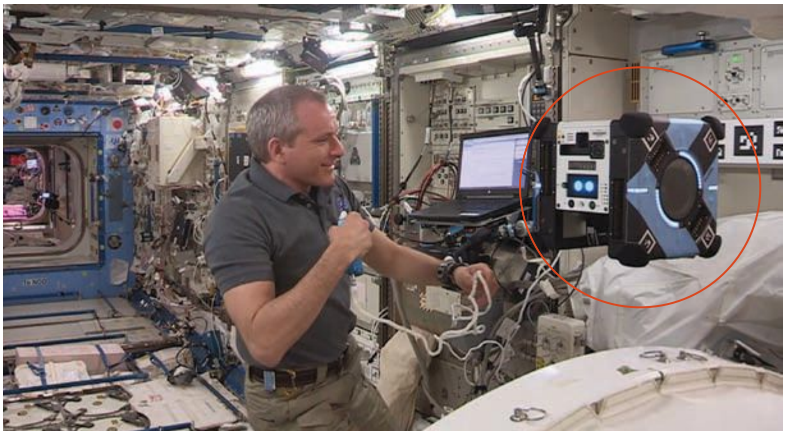
Considering the merits of all of the concepts demonstrated, in July NASA awarded a **sole-source contract for a minimal habitation module** to Northrop Grumman, stating that it was "the only NextSTEP-2 contractor with a module design and the production and tooling resources capable of meeting the 2024 deadline," in view of the progress already made in Northrop's Cygnus spacecraft development.

Nevertheless, Bigelow Aerospace demonstrated its **B330 module** in August and September at its facility in Nevada. The largest of all of the NextSTEP entrants, the module provides 330 m^3 of pressurized volume yet packs for launch within a 5 m payload fairing. A volumetric demonstration unit open to the press was built in steel rather than inflated fabric in order to sustain the Earth gravity loads.

Meanwhile, the European Space Agency and its contractors continued plans to provide **international elements to the Gateway.** In October, Airbus completed study contracts for two elements: **I-Hab**, the international living and research module; and **Esprit,** the infrastructure module that includes a propellant storage and refueling system, interface to payloads and a scientific airlock. Thales Alenia also in October separately completed study contracts for the same two elements. The space architecture firm Liquifer Systems Group, based in Vienna, worked on a subcontract from Airbus to support the habitat engineering configuration.

Besides the orbital Gateway, the **lunar surface** was the focus of other architectural attention, and a terrestrial architectural firm has taken a leading role. In April, Skidmore, Owings & Merrill released its concept for the "Moon Village," which it is planning, designing and engineering in partnership with ESA and the Massachusetts Institute of Technology. ★

Contributors: *Maria João Durão, Matthew A. Simon, Daniel Inocente and Zachary Taylor*



Robots assisting astronauts, servicing ISS and assembling

BY ERIK KOMENDERA, JIAN-FENG SHI AND GARDELL GEFKE

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

▲ **Astronaut David Saint-Jacques** of the Canadian Space Agency watches an Astrobee robot fly for the first time inside the International Space Station.
NASA

In June, **"Bumble Bee"** became the first of three Astrobee robots to fly under its own power in space. The **Astrobees** are designed to operate inside the International Space Station using electric fans for propulsion and computer vision for navigation. The robots can be equipped with a small arm that allows them to grasp handrails or carry small items to perform tasks, such as inventory, sensor surveys and mobile camera work.

Early this year, the Satellite Servicing Projects Division's **Restore-L**, which will robotically inspect, refuel and relocate a satellite not designed to be serviced, completed its spacecraft bus critical design review. In September, NASA awarded a contract to Colorado-based Maxar Technologies to add an additional payload to Restore-L that will demonstrate boom manufacturing and in-space assembly of a fully functional communications antenna with a robotic arm. In August, the division's **Robotic Refueling Mission 3** completed an initial set of tool operations, bringing in-space refueling closer to reality. ISS's **Dextre robot** operated and demonstrated the first of three tools needed to **transfer liquid methane from one tank to another**. The ability to transfer and store cryogenic fluid such as liquid methane in space could help enable human travel to the moon, Mars and beyond. Robotic Refueling Mission 3 launched to the ISS in December 2018 and, after four months, demonstrated the longest zero boil-off storage of liquid methane. In August, the Satellite Servicing Projects Division completed the development, build and delivery of the **robotic tool stowage payload**. When affixed to the outside of the ISS, the receptacle will house two **robotic external leak locator units**, developed by the division in partnership with NASA's Johnson Space Center in Texas.

In August, Russia launched a final experimental demonstration object research robot named **Skybot F-850** to the ISS for testing, where it demonstrated interaction and tool exchange in collaboration with cosmonauts Aleksander Skvortsov and Alexey Ovchinin.

In July, the India Space Research Organization launched the **Chandrayaan-2** lunar exploration mission, which included the Vikram lander and the Pragyan lunar rover. The Pragyan rover was intended to travel up to 500 meters over one lunar day and would have collected data determining elemental abundance. However, in September, the agency lost contact with Vikram as it attempted landing.

NASA's **Mars Helicopter** flight hardware completed flight testing in the 25-foot-wide (7.6 meter) thermal vacuum chamber at NASA's Jet Propulsion Laboratory in California in January. It was attached to the **Mars 2020 Rover** in August for launch in July 2020.

In May, a **power switching unit failure on the ISS** caused several subsystem power outages and grounded a SpaceX resupply launch. A high-priority removal and replacement operation was conducted in three days with the **Canadian Dextre robot replacing the failed unit and restoring the ISS to full power**. In February, Canada announced it would join NASA's **Artemis** lunar Gateway program with **Canadarm 3**, which will use artificial intelligence to operate autonomously. In August, the Canadian Space Agency awarded Canada-based MDA, the maker of the first two Canadarms, Phase A work for the Gateway external robotic interfaces of the **Deep Space Exploration Robotics program**. In June, MDA delivered the European Space Agency's Exo-Mars chassis and locomotion subsystem for the rover's launching in 2020. By the end of July, the MDA-built **OSIRIS-REx Laser Altimeter** instrument had made **2 billion measurements** on NASA's mission to sample the near-Earth asteroid Bennu.

NASA's **Active Response Gravity Offload System** was used for development and training for the ISS antimatter measurement payload, Alpha Magnetic Spectrometer or AMS-02, repair mission. The ARGOS robot simulated a microgravity environment, allowing engineers and crew members wearing fully pressurized space suits to develop and train for the complex repair procedure on a high-fidelity mockup of the AMS-02 payload. ★

Contributors: *Terry Fong, Robert Savely, Paul Valle, Stayne Hoff, Joseph Parrish and Brook Sullivan*

Supplying the space station, preparing to put humans back on the moon

BY HANG WOON LEE AND KOKI HO

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

Northrop Grumman and SpaceX completed Commercial Resupply Services missions to carry cargo to the International Space Station this year. Space X's CRS 17 and 18 launched in May and July; Northrop Grumman's Cygnus NG-11 launched in April. Phase 2 of NASA's Commercial Resupply Services contract began with the launch of Cygnus NG-12 to the ISS in November. SpaceX's CRS 19 was scheduled for December.

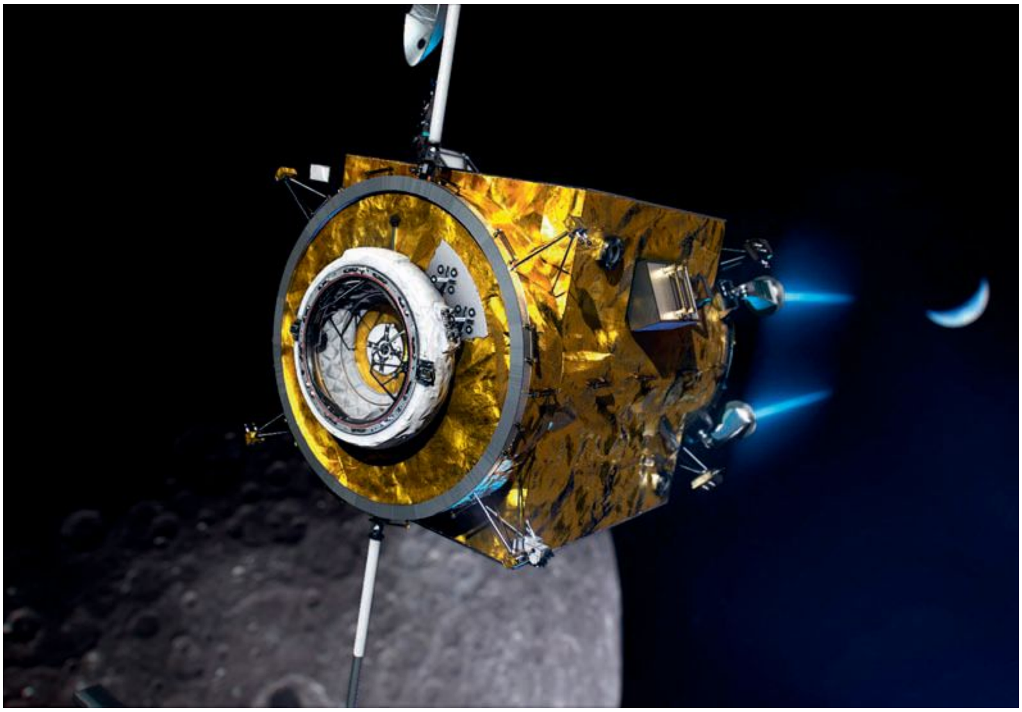
In its efforts to establish a planned space station, China deorbited **Tiangong-2** in July, marking the official end of its experimental space station mission. China is set for the launch of Tianhe for its modular space station.

NASA made a significant movement in the ongoing development of the crewed lunar spaceflight program. In May, NASA Administrator Jim Bridenstine announced that the return-to-the-moon program would be called **Artemis**, after the twin sister of Apollo. Artemis envisions the use of the lunar **Gateway** to provide sustainable transportation to the lunar surface. Gateway, in a near-rectilinear halo orbit, will be a transportation and logistics hub for supporting future crewed and cargo missions. In May, NASA awarded Maxar Technologies a contract to build Gateway's **Power and Propulsion Element module**. The PPE will provide a high-power solar electric propulsion capability. In August, NASA formally announced a request for proposals for logistics services to Gateway, encouraging **commercial partnerships** in the cislunar regime with the total offering up to $7 billion.

In February and July, NASA announced the list of scientific payloads and experiments that will fly to the moon as part of the **Commercial Lunar Payload Services program**. CLPS is a major logistics-based NASA initiative to deliver small-to-medium payloads to the lunar surface as a service that NASA and perhaps others would buy as needed. NASA is using the same commercial approach to procure a **human lunar lander** system using a public-private partnership — that is, buying a logistics service rather than owning and operating the system.

On the academic side, in September, the **Space Systems Optimization Laboratory** at the University of Illinois at Urbana-Champaign (now moved to the Georgia Institute of Technology) completed a one-year study for NASA to analyze the strategy of deploying **in-situ resource utilization** systems while considering the overall efficiency of the space logistics architecture. The study introduced a new multifidelity space infrastructure optimization framework that can perform efficient and reliable system-level architecture trade studies. Also this year, researchers at the Massachusetts Institute of Technology developed a new analysis method called **Mass, Crew time, and Risk-based Optimization of Supportability Strategies, or MCROSS**, which enables forecasting and optimization of spares mass and maintenance crew time for a given level of risk, including options for in-space manufacturing. The development effort started in 2017 as part of a NASA Space Technology Research Fellowship in collaboration with NASA's Langley Research Center in Virginia. MCROSS informs NASA technology investment and mission planning activities. ★

***Contributors:** Olivier de Weck, Andrew Owens and Robert Shishko*



▼ **The Power and Propulsion Element** of NASA's lunar Gateway, in an illustration, is planned to be a high-power, 50-kilowatt solar electric propulsion spacecraft — three times more powerful than current capabilities.
NASA

International momentum for space resources ramps up

BY LAURENT SIBILLE AND FORREST MEYEN

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.

◀ **The MiniRASSOR** and the larger RASSOR 2.0, low-gravity excavators designed for educational outreach.
NASA

The international focus on space resources is shaping the return to surface exploration of the moon and future exploration of Mars. High-level agreements of cooperation in space, including the **utilization of space resources** signed by Luxembourg with Belgium in January and with the United States in May followed by European Space Agency's **Space Resources Strategy** paved the way to agency-level agreements by Luxembourg Space Agency with NASA and ESA in October. The same month, Luxembourg Space Agency announced the establishment of a **space resource research center**.

This year also saw landing attempts on the lunar surface, including the **first far-side landing**, by China's Chang'e-4 in January. Communications failures in final approach plagued the attempts by **Israel's Beresheet** in April and **India's Vikram** in September that aimed at being the first to detect water ice in the subsurface.

In February, NASA's Science Mission Directorate selected three small agency-provided payloads specific to the detection of **water ice in the lunar polar geologic context** to be carried by the **Commercial Lunar Payload Services program, or CLPS,** under the **Artemis** program. The Near-Infrared Volatile Spectrometer System will image surface and subsurface hydration and surface composition of carbon dioxide and methane, and the **Neutron Spectrometer System** and the **Advanced Neutron Measurements at the Lunar Surface** will measure hydrogen abundance and bulk regolith composition.

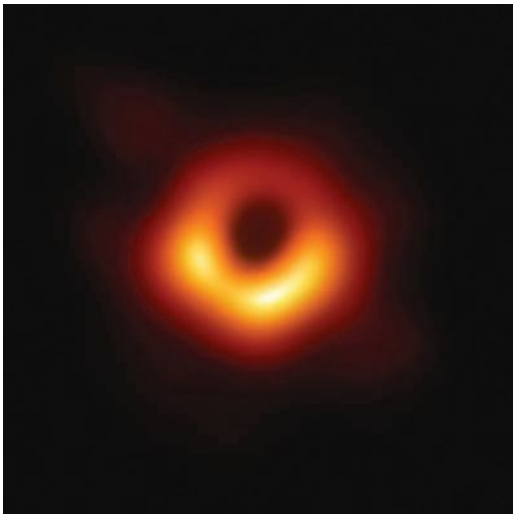
Open University in August demonstrated water production by reacting **Apollo soil samples** with hydrogen in the ProSPA miniature laboratory for an ESA lunar resource prospecting payload to be carried by the Roscosmos Luna-27 mission planned for 2025.

NASA's Glenn Research Center in Cleveland and Honeybee Robotics of New York concluded tests in September of the **Polar Resources Ice Mining Experiments, or PRIME-1.** This was done in a simulated lunarlike cryogenic temperature and hard vacuum to integrate operations of TRIDENT, The Regolith and Ice Drill for Exploring New Terrain, with the Mass Spectrometer Observing Lunar Operations for the lunar volatiles prospector payload in the CLPS program.

Our knowledge of water on Mars increased in 2019 with new results published in March by two teams of **NASA's Mars Water Mapping Projects**. The Subsurface Water Ice Mapping project at the Planetary Science Institute in Arizona produced a northern hemisphere map showing **shallow ice deposits** (within 0 to 5 meters of the subsurface) extending equatorward as far as 30 degrees north latitude in some places. Researchers at JAXA, the Japan Aerospace Exploration Agency, and the University of Paris published the first global map characterizing and mapping the surface geometry and abundance of **several hundred thousand hydrated mineral sites**, dwarfing previous maps displaying on the order of 1,000 sites.

The **Mars Oxygen In-situ Resource Utilization Experiment, or MOXIE**, was installed in the **Mars 2020 rover** in March for a launch window opening in July 2020. NASA's Planetary Science and Technology from Analog Research-funded robotic deep wireline drill, the Wireline Analysis Tool for Subsurface Observation of Northern Ice Sheets from Honeybee Robotics, reached the depth of 111 meters in Greenland equipped with the **Deep UV/Raman spectrometer** developed by NASA's Jet Propulsion Laboratory. In August, the **NASA ISRU Technology Project** team completed many critical hardware tests on scroll pumps, scroll dust filter, electrolyzers with salts-contaminated water, digging forces in compacted granular material and including an integrated design study of a full-scale oxygen production mission using carbothermic reduction of lunar polar regolith. In May, NASA's Kennedy Space Center's Swamp Works completed endurance performance tests of its **low-gravity excavator RASSOR 2.0** and created MiniRASSOR, a miniature offspring in collaboration with a University of Central Florida student navigation team.

Innovations in materials processing advanced **in-situ construction technologies** of landing pads, habitats and other long-term off-Earth structures. In May, NASA concluded the third phase of its **3D-printed space habitat challenge**. New York-based team AI SpaceFactory took home the $500,000 grand prize for its Martian habitat dubbed "Marsha." Early in the year, researchers at the University of Canterbury, New Zealand, published the development of a magnesia-silica binder system that can be produced from Martian basaltic materials with similar properties to Portland cement. Pacific International Space Center for Exploration Systems produced high-strength defect-free basalt tiles with Hawaiian materials. ★



▶ Astronomers in April released the first-ever image of a black hole. This one is 6.5 billion times more massive than the sun and is located at the center of the galaxy Messier 87. The image was made by an array of eight ground-based instruments called the Event Horizon Telescope.
Event Horizon Telescope Collaboration

Space systems deliver progress toward space economy

BY JOHN CARSTEN

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

The trend of reprogrammable communications satellites continued in 2019, with Boeing announcing in September that its "software-defined" **702X geosynchronous satellites** will dynamically allocate bandwidth.

Turning to space science, China's **Chang'e-4 lander and Yutu-2 rover** spent the year exploring the area around their landing site on the far side of the moon. The rover and lander alternated between a dormant mode during the long lunar nights and active mode during the days. The China National Space Administration, which provided regular mission updates on its website, reported in August that Yutu-2 had driven 271 meters. The January touchdown marked the first soft landing of a spacecraft on the lunar far side. Next, China plans to launch Chang'e-5, a lunar sample return mission.

In February, NASA announced the **end of the Mars rover Opportunity** mission after receiving no response from the rover since June 2018 when a dust storm temporarily enveloped the planet. The dust probably crippled Opportunity by covering its solar cells and sensors. Opportunity traveled a total of 45.16 kilometers since its arrival in 2004, NASA said.

Researchers from the **Event Horizon Telescope project** in April released the **first image of a black hole**, specifically one located 54 million light years away in the center of the galaxy M87. The image was produced by an array of eight ground-based telescopes. The breakthrough was announced in a series of six papers published in a special issue of the Astrophysical Journal Letters. "We have taken the first picture of a black hole," said Event Horizon Telescope project director Sheperd S. Doeleman of the **Center for Astrophysics Harvard & Smithsonian**. "This is an extraordinary scientific feat accomplished by a team of more than 200 researchers."

In human spaceflight, SpaceX in March launched its **Crew Dragon** spacecraft on an uncrewed demonstration flight to prepare for its first flight with a crew. The capsule's docking at the International Space Station and splashdown in the Atlantic Ocean brought NASA a step closer to restoring the country's ability to launch astronauts to and from the space station. "These are all capabilities that are leading to a day when we are launching American astronauts on American rockets from American soil," NASA Administrator Jim Bridenstine said after the mission. The mission was a milestone in NASA's **Commercial Crew program** in which contracts were awarded for Crew Dragon and Boeing's **CST-100 Starliner**. NASA had hoped to certify the spacecraft for crew flights in 2017.

In the budding space tourism sector, Virgin Galactic in August opened its Gateway to Space building at the **Spaceport America** site in New Mexico. Earlier in the year, the company announced that it was ready to move its Eve carrier aircraft, the **Virgin Space Ship Unity** passenger spacecraft, and supporting staff and equipment to the site in preparation for Virgin Galactic's first launch of space tourists. Virgin expects to begin commercial operations in 2020. Also, Blue Origin in January and May launched its **New Shepard** vehicle from Texas without passengers in preparation for its first flight with people.

In June, NASA announced that **"private astronauts"** would be permitted to fly to the International Space Station twice a year for short stays starting in 2020. The change in policy is part of NASA's strategy to "stimulate a low Earth orbit economy." Participants in these privately funded missions would have to ride on NASA-certified spacecraft, meaning the Crew Dragon or Starliner once those are certified by NASA.

The space station is not the only potential venue for those who want to visit space. Bigelow Aerospace of Las Vegas this year continued development of its Genesis modules, inflatable space habitats to be launched aboard Vulcan rockets. The startup Orion Span of California plans to build a luxury space hotel, Aurora Station, offering guests 12 days of lodging in a pill-shaped structure. ★

Space tethers to demonstrate propellantless propulsion, deorbiting satellites

BY SVEN G. BILÉN

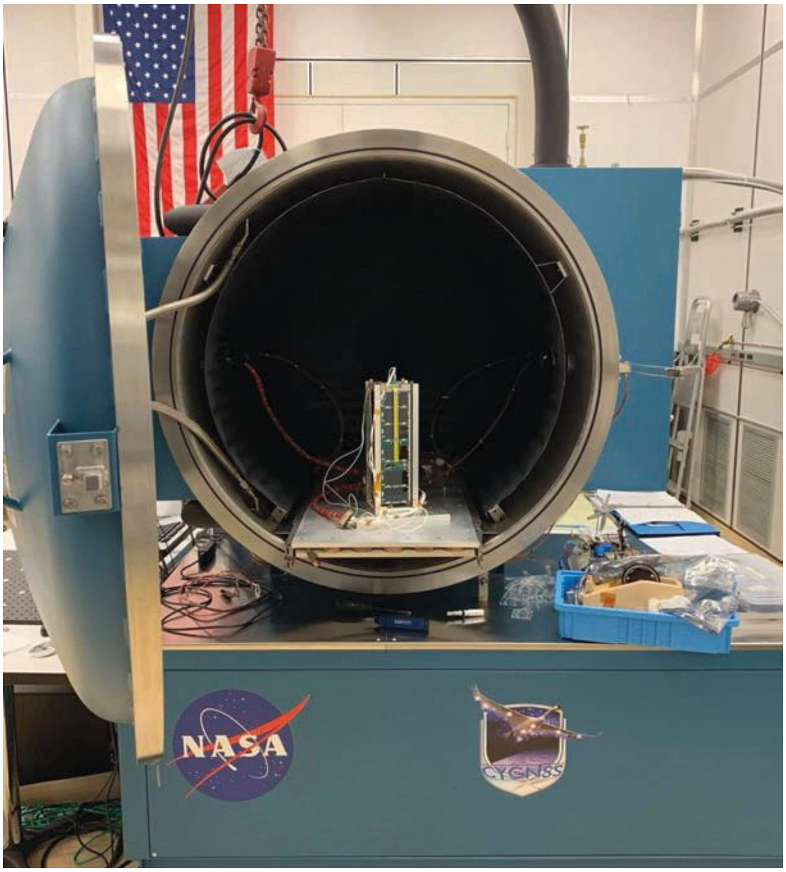
The **Space Tethers Technical Committee** focuses on the development and use of tether-based technology for space systems.

In June, a **SpaceX Falcon 9 Heavy** rocket launched into orbit the **Tether Electrodynamic Propulsion CubeSat Experiment**, a U.S. Naval Research Laboratory mission to investigate electrodynamic-tether propulsion. In orbit, TEPCE was to divide into two 1.5-unit cubesats connected by a 1-kilometer-long conducting tether. When current flows through the tether, it pushes against the Earth's magnetic field to generate drag thrust. TEPCE is instrumented to help understand **tether deployment and dynamics** and the surrounding plasma environment of its orbit.

The **E.T.PACK** project, short for Electrodynamic Tether Technology for the Passive Consumable-less Deorbit Kit, kicked off in March with three years of funding from the European Commission. Led by Universidad Carlos III de Madrid, E.T.PACK's team includes six European institutions that will develop over the next three years the **first proof-of-concept low work-function tether**, a novel type of electrodynamic tether with a specialized coating that enables natural thermionic and photoelectric emission of electrons. The low work-function tether promises **fully passive electrodynamic deorbiting technology**. E.T.PACK's overall goal is to develop a prototype deorbit kit and related software based on the tether technology.

In August, Virginia-based TriSept Corp., California-based Rocket Lab and California-based Millennium Space Systems announced **Dragracer**, a mission to demonstrate electrodynamic-tether technology to deorbit satellites. Once in orbit, Dragracer will split into two satellites, with one unfurling Tethers Unlimited's **Terminator Tape**, a conductive tether designed to produce drag to lower the satellite's orbit. The other will reenter normally. Hence, Dragracer will be able to compare how the electrodynamic tether increases drag and shortens on-orbit lifetime. It is predicted the satellite with the tether will reenter Earth's atmosphere in two to four weeks, whereas the other satellite without a tether will remain in orbit for eight months to a year.

At the beginning of October, a team led by York University in Toronto was on track to finalize its **Deorbiting Spacecraft using Electrodynamic Tethers** payload for delivery to Texas-based NanoRacks for launch from the International Space Station in 2020. The payload comprises two 1U cubesats connected via a 100-meter-long conducting bare-tape tether. Once in orbit, the two cubesats will separate, deploying the tether to determine its effectiveness as a deorbiting device. After observing the deployment dynamics, a Spindt-array cathode will be enabled, which will nominally result in system reentry within a few days. The entire mission duration is expected to be less than six months.



▲ **The University of** Michigan's Miniature Tether Electrodynamics Experiment-1 cubesat prepared for thermal vacuum testing.
University of Michigan/Twitter

In July, the University of Michigan completed fabrication of the **Miniature Tether Electrodynamics Experiment-1, or MiTEE-1**, 3U cubesat and completed vibration testing after environmental screening. MiTEE-1 is expected to fly on Virgin Orbit's Launcher One's second flight in early 2020 as part of NASA's **Educational Launch of Nanosatellites program**. For this first mission, MiTEE-1 was to use no tether but instead a deployable, rigid, 1-meter boom to measure the electrodynamics of electron current collection to a pico-/femto-scale satellite endbody (satellite mass up to 200 grams) in the Earth's ionosphere using a 200-volt variable bias power supply. The cubesat also uses an electron beam filament source to emit electrons in to the ionosphere that is characterized by a miniature Langmuir probe instrument.★

◀ Blue Origin's New Shepard booster lands after its 11th flight in May.
Blue Origin

Private space companies strive for crewed flights, lunar exploration

BY DALE ARNEY

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

SpaceX continued to advance reusability of the Falcon 9 launcher this year. In November, the company achieved the **fourth launch and recovery of the same Falcon 9** first stage. The stage powered the Falcon 9 that delivered **60 Starlink satellites** to orbit. The rocket's payload fairing was flown previously on a Falcon Heavy launch. Also, the company's **Dragon spacecraft** returned from a third mission to the International Space Station in August. SpaceX also captured two fairing halves from launches in June and August. After its inaugural demonstration flight in February 2018, **Falcon Heavy commenced commercial launches** in April with the delivery of a communications satellite to geosynchronous orbit. Throughout the year, SpaceX continued development on its next-generation launcher, **Starship**, in Texas and Florida in preparation for demonstration flights in late 2019 or 2020. **Starhopper, the test platform for Starship**, completed a 150-meter test flight in August at the SpaceX South Texas Launch Site.

United Launch Alliance this year launched Atlas V, Delta IV Heavy and the final Delta IV Medium rockets. The Atlas V launch in August was ULA's 135th consecutive. ULA's next-generation launcher, **Vulcan Centaur**, completed its final design review in May, and the company converted its Alabama factory to produce the vehicle in preparation for its planned debut in 2021.

Blue Origin flew the **New Shepard** suborbital vehicle for the 11th time in May in preparation for its first crewed flight in late 2019 or 2020. Blue Origin expanded its manufacturing facilities near Kennedy Space Center in Florida to prepare for **New Glenn**, the company's orbital launcher. Blue Origin revealed its **Blue Moon lander** and BE-7 engine in May; it foresees its initial flight in 2023. Blue Origin broke ground in Huntsville, Alabama, in January, on its **factory to build BE-4 engines**, which will be used for its New Glenn and ULA's Vulcan Centaur launchers.

NASA's **Orion** crew capsule, essential for the **Artemis program,** performed a flight test of its ascent abort motor in July. The engine section of NASA's **Space Launch System** was completed in August in preparation for its "green run" test, in which the integrated core stage will test fire its engines at NASA's Stennis Space Center in Mississippi, planned for 2020.

SpaceX and Northrop Grumman Innovation Systems continued to deliver cargo to the International Space Station as part of the **Commercial Resupply Services** contract. Sierra Nevada Corp. completed the final design review for its **Dream Chaser spacecraft**, on track to launch cargo to the ISS in 2021 on ULA's Vulcan Centaur. In March, SpaceX completed its first demonstration mission to send crew to the ISS by launching an **uncrewed Crew Dragon** to autonomously dock with the ISS and then return to Earth. Boeing's Starliner crew vehicle performed **parachute tests** in July in preparation for its planned demonstration mission in late 2019.

In August, an Ariane 5 flew the design's 105th mission after eclipsing 100 launches in late 2018. China landed the **Chang'e-4 lander and rover** on the far side of the moon in January. In the first privately funded mission of its kind, SpaceIL of Israel delivered the **Beresheet robotic lunar** lander to lunar orbit in April before its failed landing attempt. The Indian Space Research Organization delivered the **Chandrayaan 2 orbiter** to lunar orbit in August before losing contact with the Vikram lander during its September landing attempt.

Also in August, the U.S. Air Force's **X-37B reusable spaceplane** broke its previous flight record of 719 days in orbit.

After starting commercial operations in late 2018, Rocket Lab launched **Electron rockets** four times this year with hopes for more launches before the end of the year. In February, Virgin Galactic launched the first passenger in the **Virgin Space Ship Unity**, its suborbital launcher for tourism, after the Unity launched above 80 kilometers in December 2018. ★

U.S. military awards contracts for wide-ranging hypersonics projects

BY JAMES D. WALKER AND NICHOLAS J. MUESCHKE

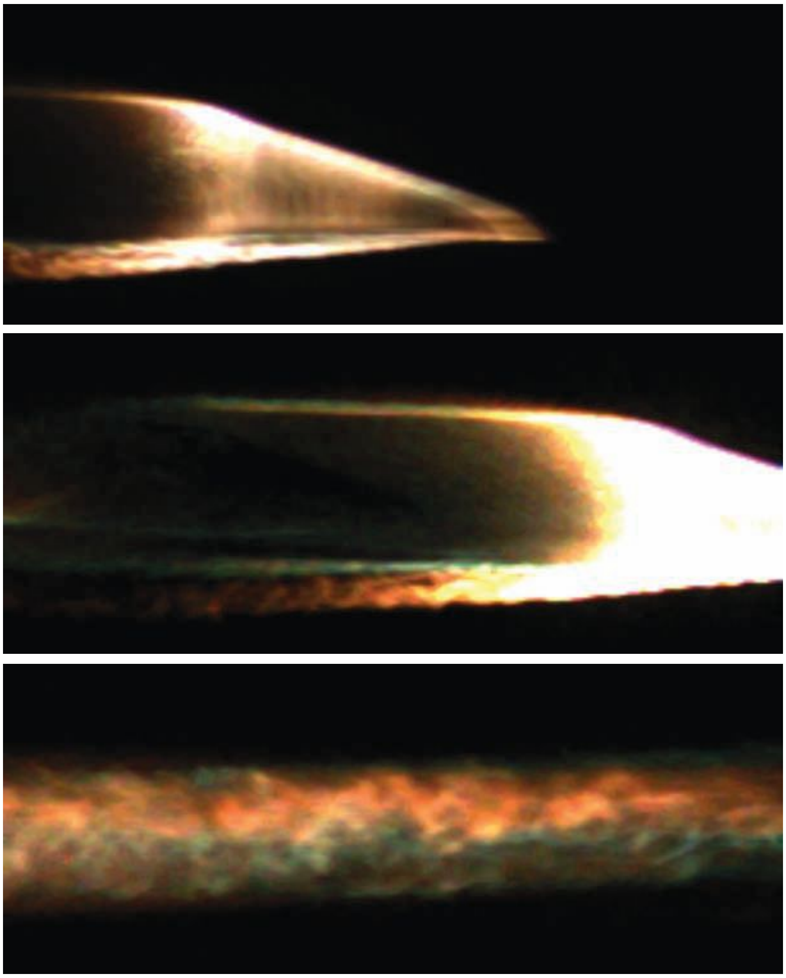
The **Weapon System Effectiveness Technical Committee** advances the science and technology of predicting, measuring, evaluating and improving the lethality of weapon systems.

Multiple U.S. government-led boost-glide and air-breathing prototype-development efforts continue to progress in the realm of hypersonics, defined as flight above Mach 5. The Conventional Prompt Strike program is moving the prototype **Common-Hypersonic Glide Body**, or C-HGB, from Sandia National Laboratories to commercial production. Specifically, in August, Dynetics Technical Solutions, based in Alabama, with subcontractors General Atomics Electromagnetic Systems, Lockheed Martin and Raytheon, was awarded a $351.6 million program to produce 20 C-HGB prototypes for the U.S. Army, Navy and Missile Defense Agency.

These glide bodies are intended mainly for testing, but the Army's goal is to deliver a residual combat capability to soldiers by 2023. This effort is part of Long Range Precision Fires, one of the Army's priorities handled under cross-functional teams. The six cross-functional teams fall under the new U.S. Futures Command, which was stood up in Austin, Texas, last year.

▼ **Sequence of high-speed** video frames from a Mach 14.8 conical flight body launched from a two-stage light gas gun into a controlled, rarefied atmosphere, looking at the signature of the vehicle and wake.

Southwest Research Institute



Also in August, Lockheed was selected for a $347 million contract to integrate at least eight of these glide bodies into a battery of **Long Range Hypersonic Weapon launchers**. Subcontractors to Lockheed Martin are Dynetics, Integration Innovation Inc. (i3), Verity Integrated Systems, Martinez & Turek, and Penta Research. The Air Force also has two ongoing hypersonics boost-glide weapons programs: **Advanced Rapid Response Weapon** and **Hypersonic Conventional Strike Weapon**. DARPA and the Air Force are also funding the **Tactical Boost Glide and Hypersonic Air Breathing Weapon Concept programs**. In support of these major programmatic efforts, progress continued on multiple other research, engineering and policy initiatives. These include programs looking to expand the national testing infrastructure, grow the hypersonics engineering talent pipeline, and increase the development and manufacturing capacity of advanced materials that can handle extreme conditions.

On the defensive side, there are ongoing programs related to defeating these maneuverable bodies. Last year MDA put out a solicitation and funded **21 $1 million studies** for defense. In August and September, five of these were selected for more work, all with roughly $4.5 million in additional funding, namely to Boeing for **Hypervelocity Interceptor Concept for Hypersonic Weapons**, Lockheed Martin for **Valkyrie Interceptor Terminal Hypersonic Defense**, Lockheed Martin for **Hypersonic Weapons System Defense Concept-Dart**, Raytheon for **Non-Kinetic Concept for Hypersonic Defense** and Raytheon for **SM-3 Hawk**.

Along with these awards, there is much discussion about a **space-based sensor layer for missile defense**. The ability to observe and track a hypersonic vehicle in flight is essential due to the missiles' maneuverability within the atmosphere.

Missile defense is progressing in other areas. March saw the first salvo test of the **Ground-based Midcourse Defense segment**: two ground-based interceptors, or GBI, were launched from Vandenberg Air Force Base in California in response to the launch of the complex intercontinental ballistic missile target from the test site on Kwajalein Atoll. The lead GBI of the two-missile salvo intercepted and destroyed the target reentry vehicle. The second, trailing GBI examined the resulting debris and remaining objects. Not finding any other reentry vehicles, the trailing GBI selected the next most lethal object and struck it. There were also continued flight intercept tests by both the THAAD and Arrow systems. ★

737 MAX grounding and ADS-B lead eventful year

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.

▲ **In July, Amazon** Prime Air filed a detailed petition to FAA for permission to operate its delivery drone under an air carrier operating certificate.
Amazon

Portions of the FAA were closed in January as a continuation of the **government shutdown** that began in December 2018. While the loss of those affected FAA services other than air traffic control was temporary, the uncertainty surrounding the events had such a destabilizing effect on staff and aviation stakeholders that Congress enacted a **two-year funding appropriation** to stabilize operations.

The crash of a **Boeing 737 MAX** commercial airliner in March, following an earlier 737 MAX crash in October 2018, resulted in the **grounding** of approximately 400 of the aircraft being flown by airlines around the world. FAA issued an "Emergency Order of Prohibition" applying to Model 737-8 and 737-9 (the 737 MAX) in March. These events precipitated **intense scrutiny** of the aircraft systems, instructional materials, pilot training and communications among the parties involved, including FAA, Boeing and 737 MAX operators. Perhaps most significantly, critics (e.g., the U.S. Office of Special Counsel) focused attention on the **certification methodology** and the interaction between the FAA oversight and the manufacturer. The scrutiny continued into the last months of the year with the fleet still grounded.

The mandate of equipping of aircraft with **Automatic Dependent Surveillance-Broadcast Out** surveillance by Jan. 1, 2020, resulted in substantial compliance, but about 25,000 of 106,000 General Aviation aircraft were still unequipped at the end of November. Without **ADS-B Out**, an aircraft would not be able to fly in much of the U.S. airspace at the beginning of 2020. Meanwhile, FAA evaluated two aircraft surveillance technologies that would allow **aircraft to safely fly in closer proximity over oceans**. Based on its evaluation, FAA committed to using one in the near term and to continue to study another for future use. Specifically, in April, FAA committed to implement by 2022 new international standards that allow reduced distances between aircraft, called **minimum separation standards**. These reduced distances would be enabled by a surveillance technology known as enhanced **ADS-Contract**. In contrast, FAA determined that the costs of using space-based ADS-B in U.S. oceanic airspace substantially outweigh the efficiency benefits.

The popularity of **small unmanned aerial systems, or drones**, for commercial and local government use again challenged **air navigation service providers** to develop rules and procedures that balance safety against the utility of these myriad applications. With the support of NASA, the FAA is moving forward incrementally to allow drones greater access to U.S. airspace, including flights over people and **flights beyond line of sight**. Giving credence to the future drone role in package delivery, **Amazon Prime Air** filed a detailed petition to FAA in July for permission to operate under an air carrier operating certificate while in October, **UPS Flight Forward** received FAA certification to operate a drone airline. In Europe, Swiss ANSP Skyguide announced in August deployment of the **Swiss U-space flight information system** for drones.

In September, American Airlines retired its **MD-80** aircraft, and Airbus announced that it would stop production of the **A380** after meeting current orders to Emirates Airlines through 2021, even while All Nippon Airways was introducing nonstop A380 service from Nikita and Honolulu. Boeing test-flew its **autonomous electric passenger air vehicle prototype** but it crashed in June in subsequent testing, setting the program back.

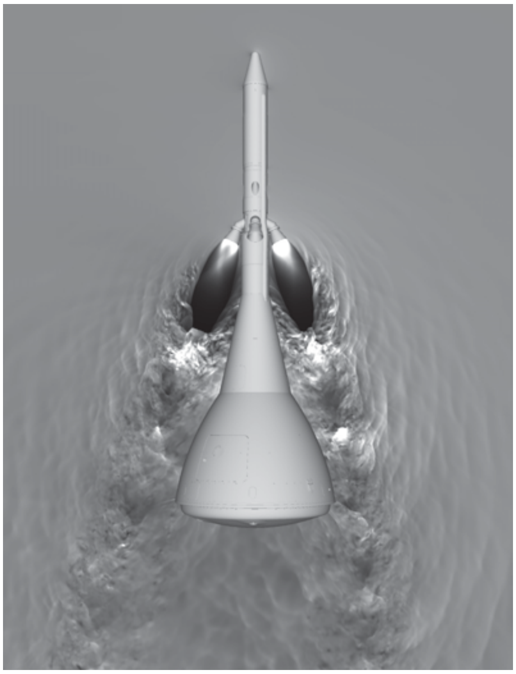
Motivated by a presidential mandate to free portions of spectrum for nongovernment use, a cross-agency team of the FAA, the Defense and Homeland Security departments, and NOAA are engaged in the **Spectrum Efficient National Surveillance Radar program**, which would allow 30 megahertz of frequency spectrum below 3 GHz (1,300 to 1350 MHz) to be released. In August, the FAA updated industry on the program, including consolidation of required service volumes that removed many terminal air traffic control surveillance services from the original program goals. ★

Contributor: *Charles Keegan*

Progress toward the 2030 vision of CFD

BY REYNALDO J. GOMEZ III, ANDREW W. CARY AND MUJEEB R. MALIK

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.



A NASA team's scale-resolving simulation of the Orion Multi-Purpose Crew Vehicle during an ascent abort scenario at transonic speed and high angle of attack in support of NASA's Ascent Abort Test-2 in July. The image shows a snapshot of pressure (black is low, white is high) on a slice through two of the abort motor nozzles.

NASA

Significant developments continued this year toward achieving the goals defined in NASA's **CFD Vision 2030 study** released in 2014. Academia made progress on algorithms and solvers for both second-order and higher-order methods. While **second-order codes** continue to dominate industrial applications, higher-order solvers are beginning to show their promise. Testing, conducted at United Technologies Research Center in February, of the **high-order discontinuous-Galerkin solver eddy**, developed at NASA's Ames Research Center in California, has demonstrated that it is an order of magnitude faster for the same level of accuracy on canonical benchmarks than existing production solvers. This demonstrates the potential for emerging **high-order scale-resolving methods** to impact the design and analysis of turbomachinery components. Development continues in the area of **automated high-order mesh generation** to enable efficient use of h-p refinement, varying the local mesh size (h) and polynomial degree (p).

The CFD 2030 vision study emphasized the importance of developing algorithms better-suited to the many core computing architectures of tomorrow toward achieving the time-and-space resolution goals for **scale-resolving simulation**. Earlier this year the **Launch Ascent and Vehicle Aerodynamics**, or LAVA, team at Ames refactored its **LAVA Cartesian framework** to better exploit these new architectures. In collaboration with the **Orion Multi-Purpose Crew Vehicle loads and dynamics team** at NASA's Johnson Space Center in Houston, the LAVA team demonstrated in June the power of this approach by producing the most detailed turbulence-resolving simulations yet of various abort scenarios.

Leveraging the same Cartesian adaptive mesh refinement infrastructure used in the Orion simulations, the LAVA team implemented the **Lattice-Boltzmann method, or LBM**, which promises to be an order of magnitude faster than traditional approaches on the same mesh, to simulate **vehicles in unsteady subsonic flows**. The team demonstrated in August that LBM can accurately predict the acoustics of a small but complex quadcopter drone in forward flight with a one-week turnaround time and no manual mesh generation effort. Coupling LBM with far-field noise propagation software enables capturing tonal noise and showed good agreement in broadband noise trends when **compared to wind tunnel microphone data**.

CFD computations by researchers at Ames and NASA's Langley Research Center in Virginia showed that **nonlinear turbulence modeling** (such as with quadratic constitutive relations or a full Reynolds stress model) is necessary to predict the size of the separation bubble in the juncture flow experiment conducted in Langley's **14-by-22-foot Subsonic Tunnel**. Areas of disagreement, particularly in the prediction of Reynolds stresses remain, necessitating additional research in turbulence modeling.

At AIAA's Aviation Forum in June, NASA's Aeronautics Research Mission Directorate announced the selection of a new technical challenge for its **Revolutionary Computational Aerosciences** effort to "develop and demonstrate computationally efficient eddy-resolving modeling tools that **predict maximum lift for transport aircraft** with same accuracy as certification flight tests." A significant fraction of the certification flight testing is done in the high-lift area of the flight envelope and use of accurate CFD tools could save hundreds of millions of dollars in new aircraft development programs by reducing flight-test requirements as well as reduce testing risk by improving the preflight characterization of the aircraft behavior. A collaborative Boeing-NASA **high-lift test on Common Research Model** began in October in the QinetiQ tunnel in the United Kingdom to provide experimental data to allow validation of CFD tools for this important area of the flight envelope. At a NASA review in September, a Stanford University team showed **wall-modeled large-eddy simulation results** for the Japan Aerospace Exploration Agency, or JAXA, standard model in good agreement with experiment for maximum lift, showing the promise for such cost-efficient scale resolving methods. ★

Hybrid electric concepts move toward demonstration

BY MICHAEL IKEDA, GOKCIN CINAR AND JOHN NAIRUS

The **Energy Optimized Aircraft Systems Integration Committee** works to promote a better understanding of energy optimized aircraft and equipment systems, from concept development to vehicle production, including relevant international academic and industrial experience.

The push toward hybrid electric solutions for aircraft propulsion, power and thermal management continued with a focus on the need for **hardware demonstrators**. In April, Collins Aerospace unveiled a $50 million investment to add **2,300 square meters of lab space** to test advanced electric power systems. "The Grid" is intended to be fully operational in 2021 and will support the design and testing of a 1-megawatt motor, motor controller and battery system.

Looking toward the regional jet market, Rolls-Royce announced in August that it began ground tests of the **2.5-MW E-Fan X generator**. At the Paris Air Show in June, United Technologies Advanced Projects announced **Project 804**, focused on flying a **modified Bombardier Dash 8-100 hybrid-electric turboprop** within three years targeted at 30% fuel savings. UTAP is replacing one of the turboprops with a parallel hybrid powertrain consisting of a 1-MW engine optimized for cruise efficiency and a battery-powered 1-MW electric motor designed for takeoff and climb assist. Also at the Paris Air Show, Rolls-Royce announced its intent to acquire Siemens' **eAircraft** business, and on Oct. 1 it announced the acquisition was complete.

On the light aircraft front, Canada-based Harbour Air announced in March a partnership with **magniX**, a research and development company based in Seattle that is developing **high power density electric motors**, to convert a **de Havilland DHC-2 Beaver** to a battery electric drivetrain. Prototype testing was planned for November with commercial flight certification targeted for 2021. In June, Los Angeles-based **Ampaire** demonstrated its **parallel hybrid electric powertrain** on a converted Cessna 337 Skymaster. The Cessna's rear engine was replaced with Ampaire's battery-powered 180-kilowatt electric motor to provide two independent sources of power, one fully electric and one traditional. Ampaire expects the aircraft to be certified by 2021. NASA also continued to progress its **X-57 program** with the August start of load testing of its high aspect ratio wing. Meanwhile, **Zunum** struggled to raise Series B funding and shut down its Bothell, Washington, headquarters in July and laid off the majority of its employees.

While demonstrations of existing technologies have been a focus, NASA announced $6 million in funding over three years for the **Center for Cryogenic High-Efficiency Electrical Technologies for Aircraft** at the University of Illinois at Urbana-Champaign. The center will pursue a fully electric aircraft centered on **cryogenic liquid hydrogen and fuel cells**.

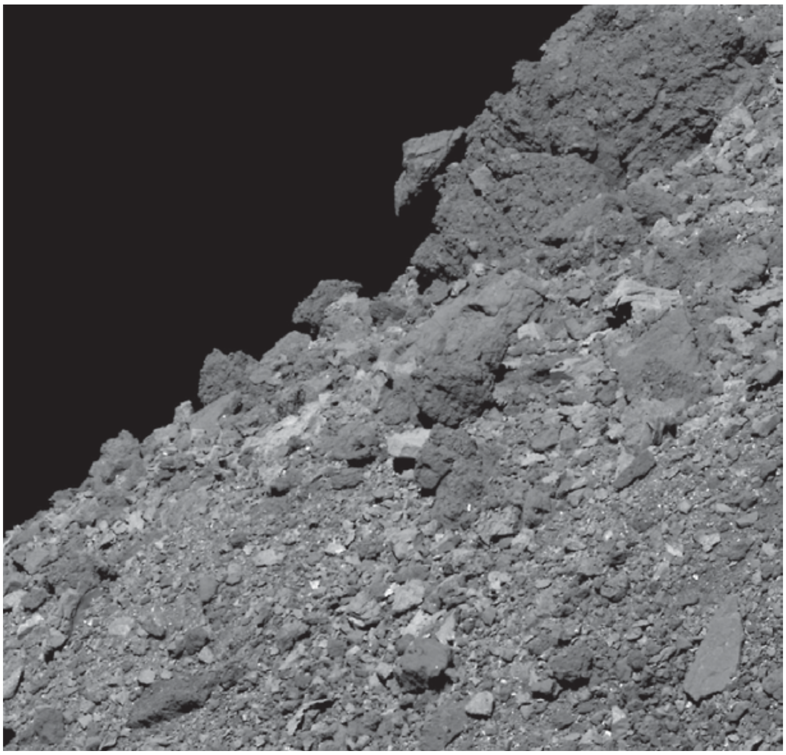
The NASA-funded **University Led Initiative Electric Propulsion — Challenges and Opportunities** project being carried out by Ohio State University, Georgia Tech, University of Wisconsin-Madison, University of Maryland and North Carolina A&T State University completed its second year of research and hardware development. This five-year project includes extensive testing and data characterization of **commercially available battery cells**, testing of a 200-kW integrated electric machine, power electronics and thermal management system, and system level aircraft assessment that integrates test data from actual hardware development, including integrated battery, thermal management system and propulsion models. ★

▼ A concept of an advanced commercial transport aircraft from the Center for Cryogenic High-Efficiency Electrical Technologies for Aircraft, which received funding from NASA to research all-electric aircraft.
University of Illinois

Space exploration focuses on asteroids

BY LEENA SINGH, SURENDRA P. SHARMA AND CHRISTOPHER MOORE

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



▲ **This picture of the** boulder-covered surface of the asteroid Bennu was taken by a camera on NASA's OSIRIS-REx spacecraft in April.
NASA

In June, OSIRIS-REx, NASA's asteroid sample return spacecraft, descended to a 1.1-kilometer orbit (about 680 meters altitude) around the asteroid **Bennu**. The low orbit made **OSIRIS-REx, short for the Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer**, the closest orbiter of a celestial object ever and Bennu the smallest object ever orbited by a spacecraft. Bennu's extremely low microgravity means that at even just 680 meters, OSIRIS-REX is in a 62-hour orbit. The spacecraft entered low-altitude orbit around Bennu in December 2018 after a five-month series of survey and remote imaging operations after first visual contact. A staged approach sequence transferred it from its safe, 50-km distant hold point to its proximal survey orbit. Toward its exploration endeavors, NASA spent much of 2019 focused on site selection for surface touchdown on Bennu later in the program as part of its sample-retrieval objective. It has identified four candidate sites from which a primary and a backup landing site were to be selected based on safety, accessibility and scientific merit.

JAXA, the Japan Aerospace Exploration Agency, conducted two landing descents of its asteroid sample-return spacecraft, **Hayabusa2**, in February and July, collecting imagery and surface and core samples for analysis; Brian May of the rock band Queen processed the images to produce stereoscopic views of asteroid **Ryugu**.

Seven years after landing on Mars, NASA's Jet Propulsion Lab's **Curiosity** rover continued to collect and telemeter new discoveries. In August, NASA reported that the rover had drilled its 22nd soil sample from the Martian surface inside the **Gale crater**. Curiosity has been heading to locations where overhead imagery from **Mars Reconnaissance Orbiter** detects areas of interest, and its in-situ findings have sometimes differed from the orbiter's aerial indications, including that water-formed clay proliferates in certain areas of the Gale crater.

Throughout 2019, NASA rolled out its **Artemis lunar exploration program**, geared toward a crewed lunar landing by 2024 to explore more of Earth's moon and establish sustainable exploration assets, thus preparing for longer-range **crewed Mars missions**. Toward Artemis, NASA has been focusing efforts on its heavy-lift **Space Launch System, the Orion spacecraft and the lunar Gateway** to orbit the moon as its backbone for deep-space exploration. To that end, in August, NASA and Boeing completed functional tests on the SLS rocket engine section and in September completed its integration with the core rocket body. Final assembly of the core stage was expected in December. The team also commenced connecting the RS-25 engines to the main propulsion systems within the engine.

The European Space Agency and NASA arrived at a consensus on Gateway's orbit, determining that it will follow a **near-rectilinear halo orbit**, a highly elliptic lunar orbit ranging from 3,000 km from the lunar center to about 70,000 km. NRHO is attractive because its relatively stable equilibrium allows nearly continuous line of sight to both Earth and the far side of the moon, allowing spacecraft parked in NRHO to serve as a communications hub between landers and ground control. **Gateway** will serve as a permanent staging post for transit between Earth and the moon and, once commissioned, will save significant fuel to ferry people or resources between Earth, the moon and beyond.

In July, the Indian Space Research Organization launched its **second lunar mission**, which entered lunar orbit in August, initiating its lander's descent in September. **Survey orbiter Chandrayaan-2** is equipped with a suite of instruments including high-resolution cameras to precisely map the lunar surface that will survey Earth's moon from polar orbit passes for a year. Its lander, **Vikram**, made a hard descent to the lunar south pole, losing ground contact thereafter. ★

Beta Technologies flew its prototype experimental tilt-rotor electric vertical takeoff and landing aircraft at Plattsburgh International Airport in New York.
Eric Adams

Flight testing begins for new urban air mobility, electric propulsion aircraft

BY KENNETH H. GOODRICH

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.

The pace of **on-demand air mobility** continued to accelerate during 2019 with multiple companies revealing new aircraft development programs and conducting initial flights of full-scale vehicles.

In January, Beta Technologies of Vermont flight-tested a piloted, **experimental tilt-rotor electric vertical takeoff and landing aircraft** at Plattsburgh International Airport in New York. Videos showed the aircraft flying in **challenging winter weather.** Also in January, Bell exhibited a full-scale replica of its **Nexus** aircraft, a tilt-duct eVTOL configuration, at the Consumer Electronics Show in Las Vegas. The Nexus has four dedicated passenger seats and a fifth seat for a pilot until self-piloting vehicle technology has been matured and certified. Boeing's Aurora Flight Sciences conducted the first flight of its full-scale, two-passenger **Passenger Air Vehicle** in January at its Virginia facility. After four test flights, the prototype was damaged in a crash following an in-flight failure of one of its six lift fans.

In May, Lilium Aircraft of Germany completed the **first flight of its five-seat, all-electric ducted-fan eVTOL aircraft**. Flown as an unmanned aircraft, the prototype demonstrated takeoff, hovering and landing. Airbus Helicopters conducted a first, unmanned, tethered test flight of its **four-seat City Airbus multicopter aircraft** in May in Germany.

Also in May, Alaka'I Technologies of Massachusetts revealed a full-scale replica of a five-passenger, **hydrogen fuel-cell-powered multicopter** with a projected endurance of up to four hours. As of the end of September, Alaka'I was working with the FAA to establish a certification basis for the aircraft; it reportedly began testing a flying prototype in May.

The past year also saw developments important to the technical realization and societal integration of **on-demand air mobility**. In January, Georgia Tech's Center for Urban and Regional Air Mobility hosted its launch event, bringing 100 academics, entrepreneurs and policymakers to Atlanta for a daylong conference to envision the specific local and state opportunities and challenges related to on-demand air mobility.

In March, the **Go Fly Prize** awarded five teams **$50,000** each in Phase II prizes. The Go Fly Prize is an international, two-year, $2 million competition to foster the realization of safe personal vertical flight. The Phase II awards were made based on quality of design and progress toward flight demonstration scheduled for February 2020.

In July, the European Union Aviation Safety Agency published "Special Condition for Small-Category Vertical Take-Off and Landing (VTOL) Aircraft." While reducing regulatory uncertainty, the special conditions established relatively **challenging requirements** for these novel vehicles. For example, for VTOL aircraft intended to operate over densely populated areas or intended for commercial passenger service, system design assurance levels are more similar to transport aircraft than small airplanes or helicopters.

In October, NASA released a solicitation for its first **Urban Air Mobility Grand Challenge and GC-Developmental Testing**. The goal of these events is to improve urban air mobility safety and accelerate scalability through integrated demonstrations of candidate operational concepts and scenarios. The solicitation seeks the participation of aircraft developers and airspace service suppliers to participate in the challenge. ★

50 years after Apollo 11, the world took note

BY BEN SARAO

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

The major history event of 2019 was the **50th anniversary of the Apollo 11 lunar landing** mission. On July 20, 1969, the first crewed lunar landing was televised, and nearly 600 million people watched worldwide. The legacy of Apollo 11 was revisited this year in several new documentary films. PBS aired a three-part series, "Chasing the Moon," a six-hour program highlighting the steps taken by the United States to accomplish the first crewed lunar mission and subsequent ones to explore the surface of the moon. This film included **never-before-broadcast material** found in archives or donated from personal collections of several astronauts.

CNN aired "Apollo 11," which included film segments that had been stowed away in government archives for nearly half a century. The film is mostly made of **newly discovered 70-mm footage** that includes intimate personal moments of the Apollo 11 astronauts being suited up prior to the launch on July 16, 1969; a segment of astronaut Neil Armstrong stepping down on the lunar surface made by astronaut Buzz Aldrin from the doorway of the Lunar Excursion Module; and select sound bites from 11,000 hours of NASA audio files from the mission.

▼ **Neil Armstrong suits** up on the morning he and fellow astronauts Buzz Aldrin and Michael Collins were launched on a Saturn V rocket toward the moon.
NASA

Aviation and aerospace museums in the United States embarked on a series of new educational programs and immersive learning exhibits and held recognition events for living legends. Throughout May and June, the **National Museum of the U.S. Air Force** in Dayton, Ohio, commemorated the 75th anniversary of D-Day. Visitors could experience the reality of the D-Day airborne invasion using HistoPad, an immersive, interactive augmented-reality tablet.

France awarded the Legion of Honor medal to three World War II veterans from Washington state at the Museum of Flight in Seattle in May. Daniel F. McAllister, a former P-38 aircraft mechanic; Stanley L. Zemo, a former demolition squad leader; and Richard A. Nelms, a former B-17 pilot, received the medals.

Notable international historical aerospace events included the China National Space Administration's **Chang'e-4** lunar lander with rover landing on the far side of the moon in January for a three-month mission. The scientific payload of the Chang'e-4 lander was powered by a radioisotope thermoelectric generator. The lunar rover was equipped with a solar panel to power the vehicle during the lunar day. The rover was able to transmit data back to Earth, despite the lack of radio frequencies on the far side, via a dedicated satellite sent earlier to orbit the moon. The lunar landing and subsequent rover relay via satellite data transmission are considered a landmark achievement for space exploration.

In April, JAXA, the Japan Aerospace Exploration Agency, separated the small carry-on impactor that had been on the asteroid explorer **Hayabusa2** for deployment to Ryugu and put the impactor into operation creating a crater on the surface.

In July, India launched Chandrayaan-2, which has a 3,500-kilogram mass, carries 13 payloads and has three elements — lunar orbiter, lander and rover — all developed by ISRO, short for the Indian Space Research Organization. India is the fourth country to attempt a soft lunar landing on the moon. On Sept. 7, ISRO reported that it had lost contact with the lander. NASA's **Lunar Reconnaissance Orbiter** made recon passes of possible lander sites on Sept. 17 and Oct. 14 but couldn't find the lander. ISRO reported that the other payloads still aboard the **Chandrayaan-2** lunar orbiter, including the Imaging Infrared Spectrometer, are performing well. ★

Apollo anniversary inspires more exploration and milestones

BY AMIR S. GOHARDANI

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

This year saw important milestones and aerospace endeavors, and among the most inspiring events were those celebrating the **50th anniversary of Apollo 11**'s historic moon landing. The mission that put humans on the lunar surface for the first time undoubtedly inspired thousands of engineers and scientists over the years and may have helped revive our quest to explore our solar system.

Commander Neil Armstrong and lunar module pilot Buzz Aldrin formed the American crew that landed the Apollo Lunar Module Eagle on July 20, 1969, and on July 20, 2019, NASA and **Vice President Mike Pence** marked the anniversary by restating the White House's plan to return humans to the moon by 2024.

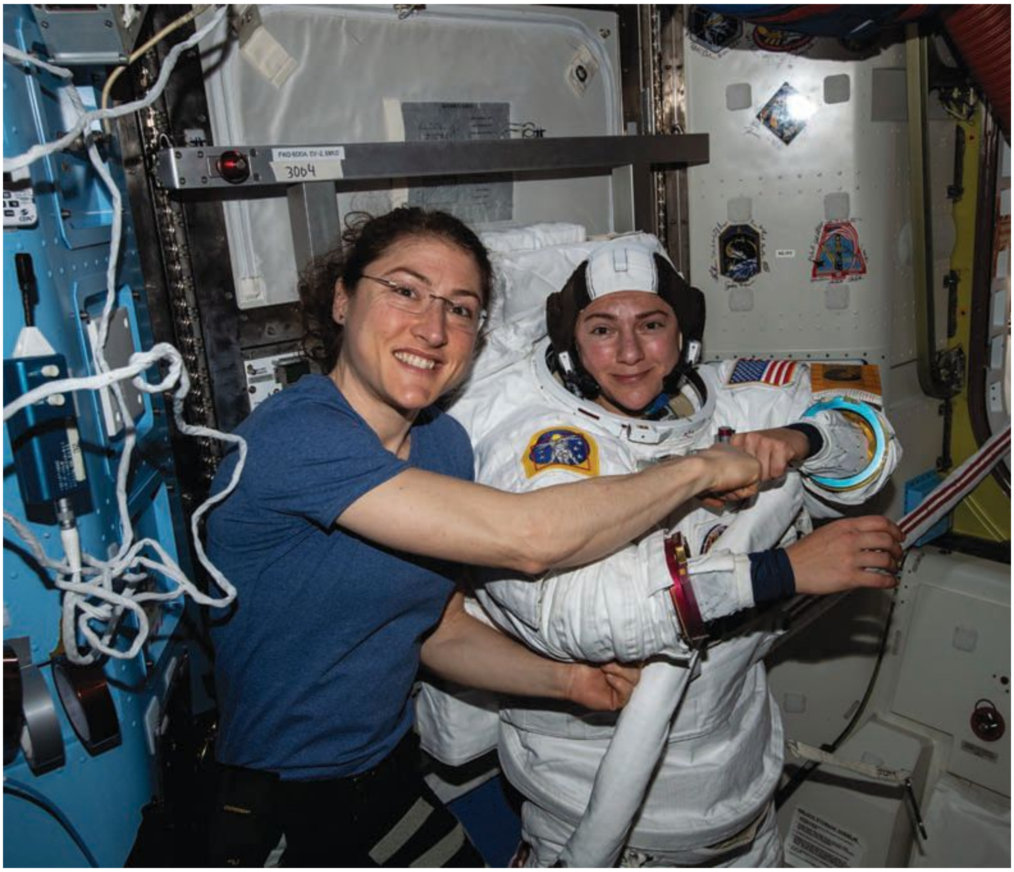
While the primary goal of NASA's new program, dubbed **Artemis**, is to land the first woman and next man on the lunar surface by 2024, a secondary objective for NASA is to collaborate with commercial and international partners to establish sustainable exploration by 2028. Success in missions such as Artemis would allow for future crewed missions to Mars.

Meanwhile, progress was made this year on the **Mars 2020 rover**, an important deep-space mission whose launch window is scheduled to open in July 2020. The rover is part of a long-term effort of robotic exploration of the red planet, and NASA's Jet Propulsion Laboratory in California announced in October that for the first time the vehicle had carried its full weight on its legs and wheels.

This year also recorded one of the busiest days in aviation history. According to Flightradar24, a real-time, air-traffic tracking service, **230,408 flights took to the skies on July 24**. Excluding certain sensitive air traffic, such as military flights, this figure represented nearly every trackable aircraft in the world, including private jets, gliders, sightseeing flights, helicopters, personal aircraft, commercial passenger flights and cargo planes. To put the number in perspective, the greatest number of flights recorded in 2017 was 190,003 on Aug. 24. Each year's low typically occurs on Dec. 25; 101,511 flights were recorded on Christmas Day in 2017.

In the quest for further space exploration, artificial intelligence identified two new "Super-Earths" in May. The **machine-learning algorithm** called AstroNet-K2, a neural network modified to hunt through data from NASA's **Kepler space telescope**, spotted the two planets, named K2-293b and K2-294b. Implementing the deep-learning algorithm capable of separating real exoplanet signals from false positives, K2-293b is about 2.5 times as big around as Earth, while K2-294b is 1.7 times as big around. These planets orbit a star about 1,300 and 1,200 light-years away, respectively.

In October, two astronauts carried out the **first all-female spacewalk**. After postponing an earlier all-female walk in March due to unavailability of spacesuits that fit both female astronauts, NASA made history by sending Christina Koch and Jessica Meir outside the International Space Station to replace a power controller. The walk lasted seven hours and 17 minutes. ★



NASA astronauts Christina Koch, left, and Jessica Meir check the fit of a spacesuit as they prepare for the first-ever all-female spacewalk.
NASA

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

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2020			
4–5 Jan	3rd AIAA Sonic Boom Prediction Workshop	Orlando, FL	
4–5 Jan	Design of Experiments: Improved Experimental Methods in Aerospace Testing Course	Orlando, FL	
4–5 Jan	Design of Electrified Propulsion Aircraft Course	Orlando, FL	
4–5 Jan	Fundamentals of Drones: UAV Concepts, Designs and Technologies Course	Orlando, FL	
4–5 Jan	Integrated CubeSat Engineering	Orlando, FL	
4–5 Jan	Integrating Program Management, Systems Engineering, and Six Sigma	Orlando, FL	
4–5 Jan	Missile Guidance Course	Orlando, FL	
4–5 Jan	Systems Thinking for Modern Aerospace Complexity	Orlando, FL	
5 Jan	75+ Years of Hypersonics Development: History, Resources, References, and Insights	Orlando, FL	
5 Jan	Additive Manufacturing: Structural and Material Optimization Course	Orlando, FL	
5 Jan	Introduction to Digital Engineering Course	Orlando, FL	
5 Jan	Space Standards and Architectures Course	Orlando, FL	
5 Jan	A Unified Approach for Computational Aeroelasticity Course	Orlando, FL	
6 Jan	Class of 2020 AIAA Associate Fellows Induction Ceremony	Orlando, FL	
6–10 Jan	AIAA SciTech Forum	Orlando, FL	11 Jun 19
14–16 Jan*	2nd IAA Conference on Space Situational Awareness	Washington, DC (icssa2020.com)	
21–23 Jan*	International Powered Lift Conference (IPLC 2020)	San Jose, CA (vtol.org/events)	19 Aug 19
25–28 Jan*	Aircraft Noise and Emissions Reduction Symposium (ANERS)	Bordeaux, France (aerospace-europe2020.eu)	31 July 19
27–30 Jan*	66th Annual Reliability & Maintainability Symposium (RAMS®)	Palm Springs, CA (www.rams.org)	
7–14 Mar*	2020 IEEE Aerospace Conference	Big Sky, MT (aeroconf.org)	
10–12 Mar*	23rd AIAA International Space Planes and Hypersonic Systems and Technologies Conference	Montréal, Québec, Canada	22 Aug 19
18 Mar	AIAA Congressional Visits Day	Washington, DC	
23–25 Mar*	55th 3AF Conference on Applied Aerodynamics	Poitiers, France (3af-aerodynamics2020.com)	18 Nov 19
27–28 Mar	2020 Region III Student Conference	Columbus,OH	31 Jan 20
27–28 Mar	2020 Region IV Student Conference	Stillwater, OK	31 Jan 20

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.).

28–29 Mar	2020 Region VI Student Conference	Portland, OR	27 Jan 20
2–3 Apr	2020 Region V Student Conference	Wichita, KS	15 Feb 20
3–4 Apr	2020 Region I Student Conference	State College, PA	16 Feb 20
6–7 Apr	2020 Region II Student Conference	Tuscaloosa, AL	21 Feb 20
16–19 Apr	AIAA Design/Build/Fly Competition	Wichita, KS (aiaa.org/dbf)	
5–7 May	AIAA DEFENSE Forum	Laurel, MD	8 Oct 19
19 May	2020 AIAA Fellows Dinner	Crystal City, VA	
20 May	2020 AIAA Aerospace Spotlight Awards Gala	Washington, DC	
25–27 May*	27th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (elektropribor.spb.ru/en/conferences/142)	
15–19 Jun	AIAA AVIATION Forum	Reno, NV	7 Nov 19
13–14 Jun	1st AIAA CFD Transition Modeling Prediction Workshop	Reno, NV	
13–14 Jun	6th AIAA Workshop on Benchmark Problems for Air Frame Noise Computations (BANC-VI)	Reno, NV	
13–14 Jun	Design of Unmanned Aircraft Systems	Reno, NV	
13–14 Jun	Missile Aerodynamics	Reno, NV	
13–14 Jun	Practical Design Methods for Aircraft and Rotorcraft Flight Control for Manned and UAV Applications with Hands-on Training using CONDUIT®	Reno, NV	
14 Jun	2nd AIAA Workshop for Multifidelity Modeling in Support of Design & Uncertainty Quantification	Reno, NV	
23–26 Jun*	ICNPAA 2020: Mathematical Problems in Engineering, Aerospace and Sciences	Prague, Czech Republic (icnpaa.com)	
9–13 Aug*	2020 AAS/AIAA Astrodynamics Specialist Conference	South Lake Tahoe, CA	10 Apr 2020
15–22 Aug*	43rd Scientific Assembly of the Committee on Space Research (COSPAR) and Associated Events (COSPAR 2020)	Sydney, Australia	14 Feb 20
24–26 Aug	AIAA Propulsion and Energy Forum	New Orleans, LA	11 Feb 20
14–18 Sep*	32nd Congress of the International Council of the Aeronautical Sciences	Shanghai, China (icas.org)	15 Jul 19
26–27 Sep*	CEAS-ASC Workshop 2019 on "Advanced Materials for Aeroacoustics"	Rome, Italy	
12–16 Oct*	71st International Astronautical Congress	Dubai, UAE (mbrsc.ae/iac2020)	
29 Oct–1 Nov*	37th International Communications Satellite Systems Conference (ICSSC 2019)	Okinawa, Japan (kaconf.org)	15 May 19
16–18 Nov	ASCEND	Las Vegas, NV (ascend.events)	

AIAA Continuing Education offerings

**Meetings cosponsored by AIAA. Cosponsorship forms can be found at aiaa.org/Co-SponsorshipOpportunities.*

A Successful IAC 2019

From 21 to 25 October, AIAA hosted the 70th International Astronautical Congress (IAC 2019) in Washington, DC. More than 6,800 attendees from 80 countries gathered to discuss the advancement and progress of space in its various features. This year's event commemorated the 50th anniversary of the lunar landing and celebrated the international accomplishments and partnerships that have become the hallmarks of space exploration.


SPACEX


IAC


SPACEIL

AIAA Announces Candidates for 2020 Election

The Council Nominating Committee has selected candidates for next year's election for openings on the AIAA Council of Directors.

Elections will open 29 January 2020. Council Nominating Committee Chair Jane Hansen and AIAA Governance Secretary Christopher Horton confirmed the names of the candidates who will appear on the 2020 ballot.

The nominees are:

Director–Region I
Steven X. Bauer, NASA Langley Research Center

Director–Region II
Kurt Polzin, NASA Marshall Space Flight Center

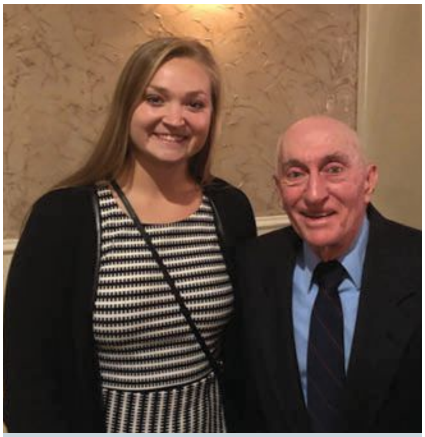
Director–Region VII
Cees Bil, RMIT University
Essam E. Khalil, Cairo University

Director–Aircraft Technology, Integration and Operations Group
Richard L. Mange, Lockheed Martin Aeronautics
Richard A. Wahls, NASA Headquarters

Director–Business and Management Group
Leslie Lake, Reynolds, Smith & Hills, Inc.

Director–Space and Missiles Group
William D. Deininger, Ball Aerospace & Technologies Corp.
Cristian N. Calugarita, Consultant
Lawrence "Robbie" Robertson, Air Force Research Laboratory

Director-Elect–Young Professionals Group
Ashlee Youngpeters, Pratt & Whitney



Marianne Cites, president of the AIAA University at Buffalo Student Branch, and Dick Grom, a 59-year emeritus member who joined IAS in 1960, were just a couple of the old and new attendees at a recent AIAA Niagara Frontier Section event.

AIAA Announces Winners of Prestigious Zarem Graduate Student Awards in Aeronautics and Astronautics

AIAA has announced the two winners of the Zarem Graduate Student Awards for Distinguished Achievement.

Johnie Sublett, a Ph.D. student at Georgia Institute of Technology, won the astronautics award for "Design and Testing of a Fault-tolerant Space Suit." Sublett also won first place in the graduate portion of the student paper competition at the 70th International Astronautical Congress, held 21–25 October in Washington, D.C.

Cole Anderson, who recently earned a master's degree in mechanical engineering from Oregon State University, won the aeronautics award for "A Test Rig for Wing Flutter Suppression via Distributed Propulsion."

AIAA Honorary Fellow Dr. Abe Zarem, founder and managing director of Frontier Associates, established the Abe M. Zarem Award for Distinguished Achievement to annually recognize graduate students in aeronautics and astronautics who have demonstrated outstanding scholarship in their field and who are pursuing graduate degrees.

Sublett

Sublett grew up in Pensacola, FL, and has always been fascinated by complex problems and smart engineering solutions. He is working on fault-tolerant space suits that can protect astronauts from many of the puncture risks associated with planetary space operations. "Space suits protect their occupants from the hostile environment of space by maintaining a safe breathing atmosphere, with a pressure bladder containing requisite internal gas pressure," he explained.

"If this pressure garment is punctured or damaged, the suit can quickly depressurize, leading to rapid loss of consciousness, asphyxiation, and death. However, if a puncture could be detected and isolated, even major suit punctures become survivable. Thus, the suit system I'm working to demonstrate includes a distributed array of pressure sensors and inflation cuffs that can detect, seal against, and isolate any punctures in the limbs of the suit."

Attending IAC 2019 put him in contact with subject-matter experts in the field of space suit design and extravehicular operations who gave him feedback about his designs. "I also had the chance to meet and chat with some of the leading experts in human spaceflight and Mars exploration, which was incredible," Sublett said.

His career goal is to work on human planetary exploration and spaceflight operations, either on the moon or Mars. "I think we're entering a golden age of space exploration. There now exists the public desire, technological capabilities, and launch infrastructure to enable humans to venture farther, and to stay longer. Humans that are alive today will be the new pioneers of our species."

Anderson

Jumping out of airplanes is what eventually led Anderson to pursue a career in aerospace engineering. He earned a skydiving license after one of his best friends introduced him to the sport.

"Spending time at the airport in small aircraft, talking with pilots, and learning about aviation fascinated me," said Anderson, who was born and raised in Palo Alto, CA. "I quickly enrolled in the Aerospace Engineering minor at Oregon State University and was immediately attracted to the engineering side of aviation. I signed up for the Design/Build/Fly team and met Dr. Roberto Albertani who later offered me a position in his laboratory for my graduate research. Dr. Albertani played a large role in the success of the aerospace engineering program at OSU and helped foster my curiosity for aviation."

Anderson's research is focused on investigating the potential for flutter suppression via distributed propulsion, meaning he is looking at how to use electric motors, instead of gas engines/turbines, along with cleverly designed wing structures, to increase aircraft efficiency and optimize cruise conditions.

"The inspiration for this idea comes from combining technology in two current NASA X-planes; the X-56 MUTT and X-57 Maxwell," he explained. "The project was selected by NASA for USRC funding and was also funded by the Boeing Professorship at Oregon State University."

Anderson said he's interested in aircraft structures and controls for his career and has been working at Altech Aerospace as a Structures Engineer where he's been doing structural substantiation and Fatigue & Damage Tolerance analysis.

"I am inspired by America's strong legacy of leading the world in aerospace technology," he said. "The current research in commercial supersonic aircraft and aeroservoelasticity is especially exciting to me. I am proud to present the result of my research and contribute to America's prestigious reputation."

For more information on the Abe M. Zarem Graduate Awards for Distinguished Achievement, visit the AIAA Awards webpage at aiaa.org/get-involved/honors-awards/awards/student-awards.

MAKING AN IMPACT

The AIAA Foundation in Action

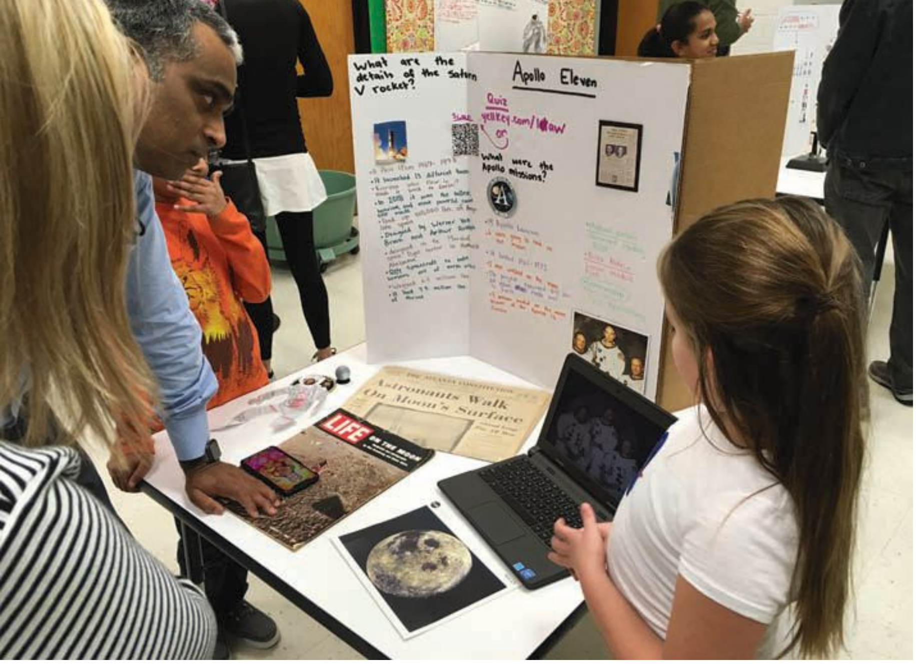
It has been another incredible year partnering with all of you to educate and inspire the next generation of aerospace professionals. Together, we spark curiosity, design hand-on programs to instruct students, and inspire youth to pursue fulfilling careers for our national and our world.

With your support, we are making a real and lasting impact. This year, we specifically:

- Distributed 72 classroom grants impacting 29,789 students
- Granted 420 First Lego League Grants involving 3,532 students
- Presented 3 K–12 Educator Achievement Awards
- Partnered with Higher Orbits to present the Apollo Series *Go For Launch*! program where 130 students participated in hands-on space activities
- Organized the annual Design/Build/Fly Competition with more than 785 students
- Held seven Regional Student Paper Conferences where 562 students participated and made 215 presentations
- Honored 60 Diversity Scholars at AIAA forums and the International Astronautical Congress
- Presented 22 undergraduate scholarships and graduate awards to deserving students to further their education

And with your continued assistance, we are looking forward to an even bigger impact in 2020!

For more information about the AIAA Foundation, visit aiaa.org/Foundation. Please reach out to Foundation Director Merrie Scott at MerrieS@aiaa.org about the Foundation's goal of impacting one million students and becoming involved or donating to the AIAA Foundation.


What are the details of the Saturn V rocket?
Apollo Eleven
Quiz
What were the Apollo missions?
LIFE
ON THE MOON
Astronauts Walk On Moon's Surface


AIAA

News

AIAA Atlanta Section Inspires the Next Generation of Aerospace Professionals

By Aaron Harcrow, Chair Emeritus, AIAA Atlanta Section
Photos by: Tony Platt

On 17 September, the AIAA Atlanta Section hosted a dinner meeting at the Delray Diner in Marietta, GA, to emphasize that success in STEM helps to identify a career path in rocketry from high school team competitions to university team competitions to full-time paying job! On hand were members from three highly successful rocketry teams in the Atlanta Section:

- Tim Smyrl, Aeronautics Team and TARC/UAS4STEM Sponsor, Creekview High School, Canton, GA
- Carson Causey and Nicolas Brophy, Co-Team Leads, Georgia Institute of Technology, Spaceport America Cup
- Jeremy Young, Propulsion Team, Generation Orbit, developing the X-60A hypersonic testbed

Smyrl has well prepared his teams of up to 40 students for the Team America Rocketry Challenge (TARC) and the International Rocketry Competition (IRC), and they are two-time winners of TARC (2014 and 2018) and world champions at IRC 2018. Team leaders present this evening were Michael Pena, Joey Gallagher, Nate Lindsey, Alex Teal, Carter Burch and Rand Johnson. The TARC team consists of up to 10 students who pay a $50 dues; the $500 budget covers entry fees, building materials, and as many composite propellant motors as possible to create two rocket classes:

- TARC: 650g max mass, carrying one chicken egg as close to 800 feet as possible in a time window of 38 to 40 seconds
- NASA student launch team: K-class impulse rocket, carrying an autonomous glider to an altitude between 3500 and 5500 feet at which time the glider will be deployed on a preprogrammed GPS flight path.

Other expenses are funded by donations from sponsors in the community. AIAA Atlanta contributed to the purchase of matching team shirts complete with the Atlanta Section logo on the sleeve!

Causey and Brophy, assisted by last year's team lead Casey Wilson, co-lead a Georgia Tech team that competes in the world's largest collegiate rocketry competition, the annual Spaceport America Cup. In their first year to compete, the team won first place in their category, hitting just shy of the altitude target of 30,000 feet with commercially bought rocket motors and placed second overall for Judge's Choice out of the ~95 teams that flew. This year they're building another two-stage rocket to hit 30,000 feet and are developing their own solid rocket motors. The annual budget of the GT rocketry club is around $20,000, with the rocket launch costing around $5,000–7,000 of that. The 14-foot-tall rocket, dubbed "Sustain Alive," reached a max altitude of 28,140 feet, and a max speed of Mach 1.17.

And to show where these high school and university rocketry programs can lead, Jeremy Young spoke about his career at Generation Orbit, where he is a member of the Propulsion Team in support of the X-60A, a development program sponsored by the Air Force Research Laboratory (AFRL). He presented a high-level overview of the X-60A program, noting that X-60A is an expendable research testbed in support of the nation's hypersonics research programs and that it is not a space launch platform and cannot deliver payloads to orbit. It will operate at speeds of Mach 5+ to collect valuable flight test data. Generation Orbit recently conducted a successful integrated hot-fire test of the X-60A propulsion system and liquid rocket engine.

Many STEM lessons learned were presented during the evening including systems engineering of a complete rocket system, FMECA, calculating mass of fuel needed to hit an altitude target, trajectory planning in varying atmospheric conditions, design and fabrication of precision parts, installing and operating radio control equipment, range safety, and data telemetry. One non-STEM lesson learned is that as rockets are made larger to go faster and higher, the cost increases astronomically! And that is why AIAA Atlanta provided financial sponsorship for the Creekview HS team during the 2018–2019 Section year and will assist both Creekview and the GT SAC team in 2019–2020.

AIAA Atlanta will follow the trajectories of these three teams as they continue to develop new rockets, enjoy successful first launches, and face challenges in future competitions. We encourage the teams to apply STEM best practices and look forward to receiving additional reports of success and awards and hearing how the Creekview HS rocketry teams members advance to Georgia Tech rocketry teams and GT rocketry team members advance to employment at Generation Orbit!

The Space Force — AIAA Space Systems Technical Committee Essay Contest

The AIAA Space Systems Technical Committee's (SSTC) annual middle school essay contest continues to improve its commitment to directly inspire students and local sections. Each year, additional local sections start parallel contests to feed into selection of national winners awarded by the SSTC.

The 2019 essay topic was "President Donald Trump announced the idea of a Space Force. What are the key advantages and disadvantages of having a Space Force and an organizational restructuring within the Department of Defense?" Seventh and eighth grade students were asked to participate. The six national winners will receive a one-year student membership with AIAA.

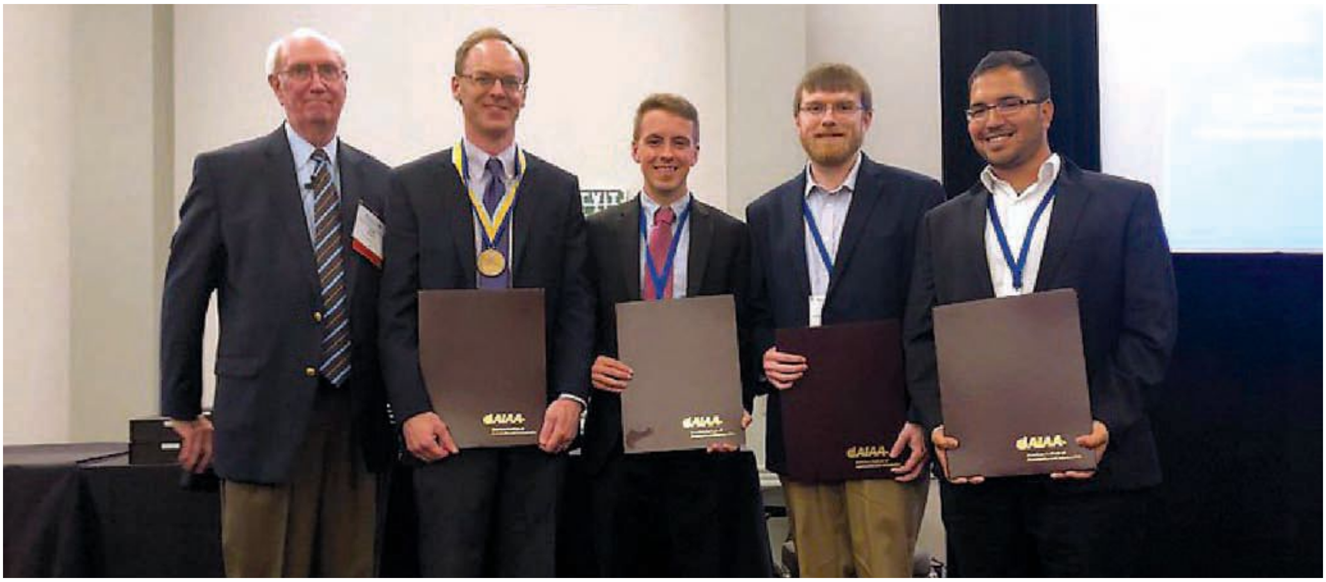
The first-place winner for 8th grade was **Erin Alvarez** (and teacher Vanessa Kowalczyk) from Levittown, NY. The second-place winner for 8th grade was David Ko from Palos Verdes, CA. The third-place winner for 8th grade is Isabella Jacobs from San Antonio, TX.

8th grade winner Erin Alvarez (left) with Astronaut Walter Cunningham

The first-place winner for 7th grade is **Claire Thorburn** (and teacher Shawna Christenson) from Palm Beach, FL. The second-place winner for 7th grade is Asher Blatt from Palm Beach, FL. The third-place winner for 7th grade is Maya Mohanty from Palm Beach, FL.


7th grade winner Claire Thorburn

All 2019 winning essays can be found on the Aerospace America website (aerospaceamerica.aiaa.org/bulletin/december-2019-aiaa-bulletin). The topic for 2020 is "How advanced can you envision space technology and exploration through the next 50 years? What do we need to do NOW to achieve that?" If you, your school, or section are interested in participating in the 2020 contest, please contact Anthony Shao (ant.shao@gmail.com) or your local section for more details.



Digital Avionics Systems Award Presented in September

The AIAA Dr. John C. Ruth Digital Avionics Systems Award was presented to the ACAS X Design Team Leaders "for the development of the Advanced Collision Avoidance System X (ACAS X) using machine learning technology, statistical risk assessment, and flight test campaigns." The presentation occurred at the 38th Digital Avionics Systems Conference in September. Tom Smith, AIAA Fellow, made the presentation on behalf of AIAA.

ABOVE (L to R): Tom Smith, and the recipients or their stand-in: Jim Kuchar (Lincoln Laboratory), Kyle Julian representing Mykel Kochenderfer (Stanford University), Paul Wood representing Joshua Silbermann (APL/APU), and Luis Alvarez representing both Wes Olson [Lincoln Laboratory] and Neal Suchy (FAA).

Call for Papers for the 2020 AAS/AIAA Astrodynamics Specialist Conference

The 2020 AAS/AIAA Astrodynamics Specialist Conference will be held 9–13 August 2020 at the Lake Tahoe Resort Hotel in South Lake Tahoe, CA. Manuscripts are solicited on topics related to space-flight mechanics and astrodynamics, including but not necessarily limited to:

- Asteroid and non-Earth orbiting missions
- Atmospheric re-entry guidance and control
- Attitude dynamics, determination and control
- Attitude-sensor and payload-sensor calibration
- Dynamical systems theory applied to space flight problems
- Dynamics and control of large space structures and tethers
- Earth orbital and planetary mission studies
- Flight dynamics operations and spacecraft autonomy
- Orbital dynamics, perturbations, and stability
- Orbit determination and space-surveillance tracking
- Orbital debris and space environment
- Rendezvous, relative motion, proximity missions, and formation flying
- Reusable launch vehicle design, dynamics, guidance, and control
- Satellite constellations
- Spacecraft guidance, navigation and control (GNC)
- Space Situational Awareness (SSA), Conjunction Analysis (CA), and collision avoidance
- Trajectory / mission / maneuver design and optimization
- Technology Anniversary: Lessons Learned and Impact
- The history of Astrodynamics: Review of seminal astrodynamical, theoretical and practical developments

In addition to the above general topics, papers are also solicited for a special session on the flight dynamics of NASA's Artemis Program, which includes research and development on the Space Flight System, Orion spacecraft, Lunar Gateway, as well as longer-term plans for crewed flights to Mars.

The abstract deadline is 10 April 2020. More information can be found at space-flight.org/docs/2020_summer/2020_summer.html.

Obituaries

AIAA Senior Member Prahl Died in April 2018

Joseph Prahl, 75, a longtime Case Western Reserve faculty member and researcher with great expertise in dynamics, fluid mechanics and thermodynamics, died 19 April 2018.

Prahl received a bachelor's degree from Harvard College in 1963, and a Ph.D. in mechanical engineering from Harvard University in 1968.

Prahl spent 40 years at Case Western Reserve in the Case School of Engineering's Department of Mechanical and Aerospace Engineering, helping with 40 master's or doctoral theses and conducting valuable research in fluid and thermal science supported by a host of federal agencies, while publishing more than 20 refereed journal articles.

Most recently, Prahl was appointed in 2007 as Case School of Engineering's first faculty director for undergraduates. Previously, he was chair of the Department of Mechanical and Aerospace Engineering from 1992 to 2007.

Prahl's was also known for his work for the U.S. space program. He took a leave of absence from the university from 1990 to 1992 to work as a payload specialist at NASA Marshall Space Flight Center in Huntsville. This work included the 13-day Columbia mission in June 1992, when Prahl helped with more than a dozen experiments in areas such as crystal growth, fluid physics, combustion, bioprocessing, space-acceleration measurement and the effects of extended duration orbit on the human body. He also assisted in experiments in combustion, surface tension, droplet dynamics and crystal growth. His background in surface-tension-driven flows and combustion played a role in his selection by NASA as a payload specialist for the mission.

He also worked with support from NASA Glenn Research Center on studies in tribology and oil-free turbomachinery; in the chemical kinetics of hydrogen-oxygen and propane-air systems; and in the use of mechanical seals for turbomachinery and space craft docking systems.

Prahl was a longtime faculty advisor to the AIAA student branch at Case Western Reserve, serving from 2009 to 2017.

AIAA Associate Fellow Panaras Died in December 2018

Dr. Argyris G. Panaras died in December 2018 at the age of 75.

Dr. Panaras served in the Hellenic Air Force from where he retired as a Colonel. He acted as a visiting professor in a number of universities and research centers, including NASA Ames Research Center, Cranfield University, German Aerospace Center, and the Hellenic Air Force Academy.

Dr. Panaras had numerous publications in leading journals, such *AIAA Journal*, *Journal of Fluid Mechanics*, and *Progress in Aerospace Sciences*, and he was the author of *Aerodynamic Principles of Flight Vehicles*, published by AIAA in the Library of Flight series.

AIAA Senior Member Wonsever Died in October

Josef A. Wonsever died on 11 October. He was 69 years old.

Wonsever obtained his private pilot license at the age of 17. He attended the Polytechnic Institute on New York graduating with a degree in Aerospace Engineering. He obtained a master's degree in Engineering Administration from George Washington University.

Wonsever worked as a rocket scientist for over 40 years for both NASA Headquarters and NASA Goddard Space Flight Center. He was Chief for Technical Assessments for the SMA Directorate, Program Manager for the GSFC Technical Standards Program, and GSFC's SMA Representative for Orbital Debris matters, making lasting contributions in Safety and Mission Assurance. In 2018, he earned NASA's highest award, the Distinguished Service Medal, for exceptional and outstanding mission support.

AIAA Fellow Vincenti Died in October

Walter G. Vincenti, professor emeritus of aeronautics and astronautics at Stanford University, who laid the engineering groundwork for flight at the speed of sound and helped develop the more efficient swept-wing airplane design still in use today, died on 11 October. He was 102.

Vincenti entered Stanford University in fall 1934, where he majored in mechanical engineering. After completing his undergraduate degree, Vincenti enrolled in Stanford's aeronautics graduate program.

After graduating with an Engineer's degree in mechanical engineering in 1940 he was invited to work at the newly developed Ames Aeronautical Laboratory. His team pioneered supersonic wind tunnel research at NACA. The mathematical framework they developed allowed for flight at the speed of sound, permanently changing aircraft efficiency and design. His findings prompted aerospace manufacturers to adopt the swept-wing aircraft model that remains an industry standard today.

Vincenti's work caught the eye of Frederick Terman, the dean of Stanford's School of Engineering. Looking to revive the Stanford aeronautics department, Terman offered Vincenti full professorship with tenure and Vincenti became a part of the Stanford faculty in January 1957.

Driven by the Space Age, Vincenti's investigation of physical gas dynamics related to atmospheric spacecraft reentry put Stanford on the map for astronautics. He built a hypersonic wind tunnel at Stanford and in 1965 co-authored the textbook *Introduction to Physical Gas Dynamics*, which remains a foundational book in the field.

In addition to his technical work, Vincenti began investigating the epistemology of technology, looking at engineering as an ethical issue. This led him to co-develop Stanford's Program in Science, Technology and Society in 1971, where he served as the director several times.

In 1990, Vincenti published a historical book looking at the epistemology of engineering, titled *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History*. This publication led to Vincenti being awarded the Engineer-Historian Award from the American Society of Mechanical Engineers in 1997.

Over the course of his career, Vincenti received many awards for his work in aeronautics and in history of technology. Most recently, he was presented with the Daniel Guggenheim Medal, for a lifetime of work in aeronautics, and a 2019 Stanford Engineering Heroes Award. Vincenti was recognized as an AIAA Fellow in 1951 and in 1956 received a Rockefeller Public Service Award for advanced study at Cambridge University, where he worked on a heat shield for spacecraft returning through Earth's atmosphere. For his devotion to students and skill as a teacher, he was awarded Stanford's Lloyd W. Dinkelspiel Award for outstanding service to undergraduate education in 1983. In 1998, Vincenti was honored for his contributions to technological history with the Leonardo da Vinci Medal, awarded by the Society for the History of Technology.

AIAA Past President and Honorary Fellow Picard Died in October

Dennis J. Picard, former CEO and chairman of Raytheon, died on 21 October. He was 87.

An Air Force airman after high school, Picard served as a radioman and took correspondence courses. Having graduated from the RCA Institute in New York as a licensed broadcast engineer, Picard ran his own repair business in Rhode Island before being hired at Raytheon.

Picard worked at Raytheon during the day and went to Northeastern University's engineering school at night, graduating cum laude in 1962 with degrees in electrical engineering and management. He rose through the Raytheon ranks to become a company vice president in 1976 and deputy general manager of Raytheon's Equipment Division in 1982.

In 1983, Picard was tapped to lead Raytheon's Missile Systems Division, and specifically, to help complete the Patriot defense system. He helped turn around the program, which was then designed to defend against aircraft, and championed its development as an anti-missile system.

Picard became Raytheon CEO in March 1991, shortly after Patriot rose to fame during the Gulf War. As spending on national defense spending dropped in the early 1990s, Picard decided Raytheon would be a buyer, not a seller. He led the acquisition of both the Hughes and Texas Instruments defense units for $12.5 billion within 10 days of each other in January 1997. These acquisitions doubled the size of Raytheon, allowing it to become one of the world's largest defense contractors.

He retired as CEO in December 1998 and as board chairman in July 1999.

Mr. Picard's military-related honors included being inducted into the Army's Order of Santa Barbara, along with receiving Fleet Admiral Chester W. Nimitz Award from the Navy League of the United States, the John W. Dixon Medal from the Army, and the John R. Allison Award from the Air Force Association.

He also was a member of the National Academy of Engineering, served as president of AIAA (2001–2002), and was a life fellow of the Institute of Electrical and Electronic Engineers.

AIAA Past President and Honorary Fellow Richardson Died in October

Donald W. Richardson died on 24 October 2019. He was 92 years old.

At the age of 18, he enlisted to serve in World War II as an Army Sergeant in charge of a mortar crew in Italy. He later continued his service as a Navy Reserve Captain.

He graduated from Georgia Tech with a degree in aeronautical engineering in 1951. He went on to earn a master's degree from Newark College of Engineering (1958) and his Ph.D. in engineering from California Coast University (1978).

Richardson had a formidable career with more than 64 years of technical and managerial experience in FAA, Department of Defense, U.S. Coast Guard, and NASA navigation, landing, air traffic control and aircraft systems design, development, and test. He is considered one of the fathers of the U.S. air traffic control system.

He also performed at technical and managerial levels in private industry throughout his entire career, as an engineer, research pilot, and corporate executive. For over 40 years Richardson was directly and continuously involved in all facets of the technical and operational issues relating to the FAA's mission including its Capital Investment Plan (CIP) and Research, Engineering, and Development (RE&D) Plan.

He worked for SAIC beginning in 1984 until his retirement in 2005, serving as SAIC Corporate Vice President with concurrent responsibility as Manager of the Air Transportation Systems Operation. In this latter capacity, he was responsible for the acquisition, staffing, and technical management of all civil aviation-related programs within the Applied Technology Systems Group of SAIC. In addition, he was assigned corporate responsibility for coordination of all SAIC civil aviation and FAA-related program activities.

In 2005, Richardson formed Donrich Research, Inc., an aviation consulting firm that conducted technical and marketing research for aerospace firms.

Over the course of his career he presented over two dozen papers at technical conferences. Richardson joined AIAA in 1948 and was an active member, serving on or chairing numerous committees, including the Aerospace Traffic Management Integration and Outreach Committee and the Institute Development Committee. He served as president of the Institute from 2004 to 2005. Richardson was awarded the AIAA Distinguished Service Award in 2012, as well as the AIAA Sustained Service Award in 2001.

He also is one the few Americans to be named an Honorary Fellow of England's Royal Aeronautical Society.

The Yvonne C. Brill Lectureship in Aerospace Engineering

This premier lecture emphasizes research or engineering issues for space travel and exploration, aerospace education of students and the public, and other aerospace issues such as ensuring a diverse and robust engineering community.

Candidates should have a distinguished career involving significant contributions in aerospace research and/or engineering and will be selected based on technical experience, originality, and influence on other important aerospace issues such as ensuring a diverse and robust engineering community.

The award includes a $1,000 cash prize and a $1,000 travel stipend.

The lecture will be held at the National Academy of Engineering building in Washington, DC, in October 2020.

Yvonne Brill receiving the National Medal of Technology and Innovation from President Obama at the White House in 2011.

NOMINATION DEADLINE: 1 FEBRUARY 2020

For more details and nomination form, please visit

aiaa.org/brill

NATIONAL ACADEMY OF ENGINEERING

Sponsored by AIAA with the participation and support of the National Academy of Engineering

AIAA SHAPING THE FUTURE OF AEROSPACE

ASSISTANT PROFESSOR FACULTY POSITION

The Department of Aerospace Engineering and Mechanics at The University of Alabama invites applications for an assistant professor faculty position. Areas of interest include, but are not limited to, the general area of space/astronautics, computational fluid dynamics, or other area of aerospace engineering or mechanics. Candidates must demonstrate a clear potential to successfully pursue and attain grants from external funding sources. An ability to collaborate with existing faculty, both within the Department and the College of Engineering, in the key focus areas is also highly desirable.

The University of Alabama currently enrolls over 38,000 students and employs over 2,000 full and part-time faculty members in thirteen colleges and schools. The College of Engineering is comprised of seven academic departments with over 6,000 students, and the College will be home to more than 150 tenure/tenure-track faculty following the current search. The College also houses nine research centers and is active in the University's four new research institutes. The College occupies well over a half million square feet of state-of-the-art facilities, including the $300 million Shelby Engineering and Science Quadrangle, completed in 2014, and the newly reopened $22 million renovated HM Comer. The Carnegie Foundation has recognized The University of Alabama with its Very High Research Activity status (formerly known as R1 status).

Applicants must have an earned doctorate in aerospace engineering, engineering mechanics or a closely related field. Applicants are to identify the specific area of interest and submit a resume, teaching and research statements with future goals and a list of at least three references. Review of applications will begin immediately and continue until the position is filled, with an expected start date of August 16, 2020. Electronic submission of application materials via The University of Alabama employment website is required (**facultyjobs.ua.edu**, requisition number 0812234). 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, **mbarkey@eng.ua.edu**.

The University of Alabama is an equal opportunity affirmative action, Title IX, Section 504, ADA employer. Women and minorities are encouraged to apply. Salary is competitive and commensurate with experience level.

College of
Engineering
Aerospace Engineering and Mechanics

KU DEPARTMENT OF AEROSPACE ENGINEERING
The University of Kansas
School of Engineering

Aerospace Engineering, University of Kansas

The University of Kansas Aerospace Engineering Department invites applications for a tenure track faculty position at the rank of Assistant Professor in the area of Aerospace Propulsion. The Aerospace Engineering Department is seeking to expand in the area of aerospace propulsion including but not limited to gas-turbine engines, turbomachinery, hybrid electric, rocket propulsion, and related areas. The ideal candidate will have substantial experience and a continuing interest in the development and design of aerospace propulsion systems.

Applications are sought from candidates with earned doctorates in Aerospace Engineering or closely related fields by the time of appointment. The successful candidate will be results-oriented, have a record of superior scholarship, have a promising vision for externally funded research, have experience in externally funded research commensurate with the rank of appointment, develop or maintain an externally funded research program, and teach high-quality courses at both the undergraduate and graduate levels. Research productivity at KU is evaluated with respect to publications in respected academic journals as well as success in acquiring external research grants, and financially supporting and mentoring PhD and MS students. The University of Kansas School of Engineering and the Department of Aerospace Engineering value Diversity, Equity, and Inclusion. We seek candidates who can contribute to fostering an inclusive culture.

Review of complete applications will begin on January 1, 2020, and continue until the position is filled. The successful candidate must receive valid U.S. work authorization prior to the specified start date, August 18, 2020. Salary is commensurate with experience.

For additional information or to apply, go to **https://employment.ku.edu/academic/15643BR**. Applications should include a letter of application, curriculum vitae, three references, a statement of research interests and future plans, and a statement of teaching interests and future plans including efforts to diversify the field of engineering. KU is an EO/AAE. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex (including pregnancy), age, national origin, disability, genetic information or protected Veteran status.

1919

Dec. 22 Based on the military 0/400 and V/1500 heavy bombers, the first Handley-Page W.8 airliner makes its inaugural flight. Powered by two Napier Lion engines, each producing 450 horsepower, the W.8 can carry 16 passengers 800 kilometers at an average speed of 140 kph. Its plush interior has curtains, carpet, electric lights and a toilet. C.H. Barnes, **Handley Page Aircraft Since 1907**, pp. 169-172.

During December
Robert H. Goddard's treatise "A Method of Reaching Extreme Altitudes" is published as part of the Smithsonian Miscellaneous Collections, Vol. 71, No. 2, but it is not released until Jan. 10, 1920. Although written in dry scientific language, the paper creates huge excitement in the press because of Goddard's mention of a rocket that could be sent to the moon. Goddard is merely presenting a hypothetical case to demonstrate the maximum achievement of one of his solid-fuel, unmanned rockets if it uses the stage or step principle. From this time, Goddard receives numerous requests from volunteers to ride in his rocket to the moon and to Mars. Esther C. Goddard and G. Edward Pendray, eds., **The Papers of Robert H. Goddard, Vol. I**, pp. 337-408.

1944

Dec. 1-16 The Jet Propulsion Laboratory launches 24 experimental Private A rockets at Camp Irwin in the Mojave Desert as part of Project Ordnance from the California Institute of Technology, to test basic missile design, handling and boost separation techniques for the Army Ordnance Department. The Private A is a standard solid-fuel jet-assisted takeoff rocket with four 4.5-inch ordnance rockets as the booster; it has 1,000 pounds (4,400 newtons) of thrust, is 30 seconds in duration, and has an average range of 16 kilometers. W. Ley, **Rockets, Missiles, and Space Travel**, pp. 250-251.

Dec. 4 Three Consolidated Liberators of the Royal Air Force's Transport Command break the West-East Atlantic crossing record for big bombers carrying full loads of passengers, cargo and mail. The 5,000-kilometer flight lasts 10 hours, 31 minutes, beating the old record by 55 minutes. **The Aeroplane**, Dec. 15, 1944, p. 666.

Dec. 13-14 It is decided in a meeting of the U.S. Army Air Forces and the National Advisory Committee for Aeronautics, NASA's predecessor, that rocket, not jet, engines should power the planned X-1 supersonic research aircraft. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 49.

Dec. 14 The Short Shetland, the United Kingdom's largest military flying boat, makes its first flight. It has fully loaded weight of 59,000 kilograms, a maximum payload of 6,350 kg, a range of 6,400 kilometers and a top speed of 423 kph. It can carry 70 passengers, but it is configured to carry no more than 40, although in great comfort. **Shorts Aircraft Since 1900**, pp. 390-398.

Dec. 14 The Avro Lancaster 1 Aries becomes the first Royal Air Force plane to fly around the world. The flight's main mission is to study navigation and to demonstrate the latest equipment likely to be used in the Pacific region. The Lancaster I, powered by four 1,280-horsepower Rolls-Royce Merlin 24 engines, flew 75,600 kilometers in approximately two months. **The Aeroplane**, Dec. 22, 1944, p. 686.

Dec. 17 Maj. Richard Bong, the most successful fighter pilot in the U.S. Army Air Corps, achieves his 40th and final victory, downing a Nakajima Ki-43 "Oscar" while flying a Lockheed P-38 Lightning fighter at the end of his third tour of duty. David Baker, **Flight and Flying: A Chronology**, p. 299.

Dec. 18 The German rocket-powered Bachem Ba 349 Natter interceptor aircraft is flown for the first time in an unpiloted test. Later Natters are piloted. This radical, vertically launched point defense fighter is powered by a single Walter 109 liquid-fueled rocket, which produced 17,000 newtons (3,750 pounds) of thrust with four Schmidding 109-533 solid-fuel boosters strapped to the rear fuselage each producing 12,000 newtons (2,640 pounds) of thrust for 10 seconds during launch. The boosters were designed to be jettisoned. J.R. Smith and Antony Kay, **German Aircraft of the Second World War**, pp. 55-59.

Dec. 21 Gen. Henry H. "Hap" Arnold becomes General of the Army, the only air officer to hold this five-star general's rank. F.K. Mason and M. Windrow, **Know Aviation**, p. 50.

During December 1944
The Lafayette Escadrille of World War I fame is reportedly reformed by the Armée de L'Air, with French pilots equipped with Republic P-47 Thunderbolts. **The Aeroplane**, Dec. 29, 1944, p. 719.

1969

Dec. 3 U.S. President Richard Nixon announces the appointment of Apollo 11 astronaut Neil Armstrong, the first man on the moon, as chairman of the Peace Corps. NASA, **Astronautics and Aeronautics, 1969**, p. 42.

Short Sunderland Mk V

Dec. 4 Hugh Oswald Short, the last survivor of the three Short brothers who in 1908 founded the world's first company to make production airplanes, Short Brothers, dies at 87. In 1910 Hugh Oswald designed gas compartments, automatic valves and pressure gauges for the first British rigid airship, Mayfly. He invented, designed and produced the first stressed-skin all-metal aircraft. In 1924 he began the design of the first all-metal stressed-skin flying boat. Later, he directed the designs of such aircraft as the Short Singapore 1 and the Empire and Sunderland flying boats. **Flight International**, Dec. 11, 1969, p. 897.

Dec. 5 Claude Dornier, the German airplane designer and founder of Dornier Flugzeugwerke (Dornier Airplane Works), dies at 85. Dornier was heavily involved in the development of all-metal flying boats. Later, he was devoted to the development of short takeoff and landing technology, culminating in the Do31, the first vertical and/or short takeoff and landing jet transport. **Flight International**, Dec. 11, 1969, p. 897.

Dec. 7 Astronomers announce that the universe might be several times larger than previously believed, based on observations made by the OAO 2, short for Orbiting Astronomical Observatory 2, satellite launched a year earlier. The satellite had the first space telescope, nicknamed Stargazer. The satellite also found that many galaxies are much brighter in ultraviolet radiation than expected. **NASA Release 69-156**; NASA, **Astronautics and Aeronautics, 1969**, p. 403.

Dec. 8 The scientific attaché at the U.S. Embassy in Paris accepts the Prix Pierre Guzman (Pierre Guzman Prize) on behalf of Apollo 11 astronauts Neil Armstrong, Buzz Aldrin and Michael Collins. It's one of the world's first astronautical awards and was established by Anna Emile Guzman in 1889 for the first people to find the means of communication with a heavenly body — Mars excluded. Until that achievement, the award was to be given for significant contributions to astronomy. The prize excluded Mars, since during Guzman's time, many people believed that Mars was inhabited and communication with that planet would not be a difficult enough challenge. **Washington Post**, Dec. 9, 1969, p. A23; Frank H. Winter, **"The Strange Case of Madame Guzman and the Mars Mystique"; Griffith Observer,** Vol. 48 (February 1984), pp. 2–15.

Dec. 11 The Air Force's YF-12A supersonic aircraft, a twin-seat version of the secret Lockheed A-12 single-seat reconnaissance aircraft, makes its first flight from Edwards Air Force Base in California to initiate a joint NASA-U.S. Air Force program to advance knowledge of high-performance flight. NASA, **Astronautics and Aeronautics, 1969**, p. 405-406.

Dec. 25 The Soviet Union's Interkosmos 2 is launched on a Kosmos 2 rocket from the Kapustin Yar cosmodrome. The satellite is designed for ionospheric research and contains experiments from Bulgaria and Czechoslovakia, as well as an onboard computer from East Germany. **Aviation Week**, Jan. 19, 1970, p. 22.

During December 1969

• The Hawker Siddeley Trident 3B jet transport makes its first flight from the company's Hatfield, England, production facility. This version of the three-engined airliner features a stretched fuselage and seating for up to 180 passengers. Since the Trident is slightly underpowered, the 3B also features a booster engine mounted above the tail-mounted engine — effectively making it the only four-engined tri-jet in the world. **Aviation Week**, Jan. 12, 1970, p. 32.

• The television-guided air-to-ground Maverick missile, developed by Hughes Aircraft Co., in its first guided flight test strikes and destroys a tank in the desert near Holloman Air Force Base, New Mexico, after being fired from a McDonnell Douglas F-4D Phantom II jet interceptor and fighter-bomber in a steep dive. **Aviation Week**, Jan. 5, 1970, p. 22.

1994

Dec. 3 After three years of testing by NASA's Langley Research Center, the FAA and the aerospace industry, the Bendix RDR-4B wind shear warning device is approved for commercial use. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 606.

Dec. 9. NASA selects Kathryn Hire for the astronaut corps, the first person from the Kennedy Space Center workforce. Hire is a contract employee for the Lockheed Space Operations Co. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 607.

Dec. 12 Astronaut Stuart Allen Roosa dies at the age of 61. Roosa was the command module pilot for Apollo 14 in 1971 and was one of only six astronauts to orbit the moon solo. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 609.

DANIEL "DEEJAY" RILEY, 29

Archinaut deputy program manager at Made In Space

A satellite beam segment made by Archinaut One's printer.

Deejay Riley grew up in Mountain View, California, working on cars with his father. No one was surprised when in college he joined San Jose State University's Formula Society of Automotive Engineers to build race cars. Riley still loves cars, but after a college internship he was hired by Made In Space, the "off-Earth" manufacturing pioneer based in his hometown. The company is best known for remotely operating two 3D printers aboard the International Space Station. Riley helps manage development of Archinaut One, a satellite that in 2022 will attempt to 3D-print a pair of 10-meter-long solar arrays and install them on itself with a robotic arm.

Landing a job ▶ Growing up, I spent a lot of time with Legos, building and creating things. When I got older, my dad and I rebuilt the engine in what ultimately became my first car. I enjoyed taking things apart and understanding how they worked and why. My dad was a pilot who owned a small airplane. I was always involved in helping him maintain and fly the plane. Coming out of high school, I didn't know what type of engineering I wanted to do. I spent a couple of years at Foothill College [in Los Altos Hills, California] and left with my associate degree in physics and engineering. Then, I went to San Jose State where I earned a mechanical engineering degree with a focus in mechatronics [a combination of mechanical and electrical engineering and often robotics]. Toward the end of my college career, I realized I needed a more formal internship. When I saw an opportunity from Made In Space, it sounded really interesting. At Made In Space, I've gotten to do a lot of really amazing things in my 20s, including having functioning hardware on the International Space Station.

From technical work to budgeting ▶ I'm usually involved with helping the engineers set technical direction, looking at data and making decisions. Like a typical deputy program manager, I also work with subcontractors, making sure that everybody has the information they need when they need it and managing the program's schedule and budget. At the end of the day, my job is to help the program manager make sure the program is successful. The work we're doing at Made In Space is setting the foundation and creating the technology that will help us expand and colonize our solar system and other planets in a unique and creative way. Archinaut is a good example because it is changing the way we think about manufacturing or interacting with satellites. The driving load for most satellites is the launch, but we can build the satellite in situ. That saves a lot of mass and ultimately cost.

Space in 2050 ▶ I think that we will be living and working in space on a larger scale than we currently are. I expect that you will see an entire section of the International Space Station or what comes after the space station as a manufacturing laboratory that is using the microgravity environment for manufacturing things to benefit Earth as well as in-space technologies. In parallel, we will be taking the beginning steps of our long-term presence in or on other planets such as the moon and Mars with the help of Made In Space technology. ★

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