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AEROSPACE
★ ★ ★ AMERICA ★ ★ ★

2018
YEAR IN REVIEW

DECEMBER 2018 | A publication of the American Institute of Aeronautics and Astronautics | aerospaceamerica.aiaa.org

AIAA
SHAPING THE FUTURE OF AEROSPACE

Airbus' BelugaXL flies for the first time in France.
Story, Page 34.

THE YEAR IN REVIEW

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

ON THE COVER

Dummy payload: Elon Musk's Tesla Roadster and the Starman mannequin (an empty spacesuit) were photographed as they headed off toward the asteroid belt. New rockets typically prove themselves by carrying non-descript mass simulators, but Musk saw an opportunity to market Tesla and the company's commercial spacesuit by putting them aboard the Falcon Heavy rocket that debuted in February. "You can tell [the photo series is] real because it looks so fake," he said after the launch. The photo on the cover was taken by a camera on the pedestal-like payload adapter that holds the Roadster.

AEROSPACE AMERICA

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YEAR IN REVIEW

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AIAA
SHAPING THE FUTURE OF AEROSPACE

NASA

▲ **The Mars Helicopter,** seen in a screen grab from an animated video, will travel with the Mars 2020 rover.

Putting technology to work

Elon Musk's Starman-in-Roadster was an irrestible photo to put on the cover of this special year-end issue of Aerospace America. For me, this shot is more than just colorful proof of SpaceX's engineering prowess or the marketing genius of turning a space launch into an advertisement for Tesla.

Starman makes me think of the years of research and development that laid the ground work for this achievement and many others in 2018. I think of the professors who taught the students who are now making these things happen at SpaceX and elsewhere. I think of the yet-to-be told stories and dramas unfolding behind the scenes at young companies, government agencies and universities. I think about the seeds for future triumphs that are contained in the R&D described in these pages, and how these articles are written by the very AIAA members who will contribute to making many of them happen.

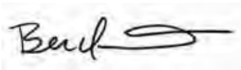
Starman tells us something else, however. Bringing R&D to fruition in a way that changes lives is always going to require strong personalities and creativity beyond the lab, vacuum chamber or flight line. For SpaceX, a disappointment, such as dumping the Falcon Heavy core rocket in the ocean, is starting to feel like a scene setter for the next success. Have you ever asked a teenager if they know who Elon Musk and SpaceX are? Try it. Lots of them do.

What SpaceX is doing for outer space, a host of urban air mobility companies are trying to do for our daily commutes. There will be setbacks to get past, for sure. Like SpaceX in its early years, these entrepreneurs are facing skeptics behind the scenes who are questioning the feasibility and realness of their ventures. Looking at the successes of the space sector, the thought of regular people going airborne no longer sounds quite so outlandish.

Mixing outer space with urban mobility might sound like an odd case to make, but as is shown in these pages, converging like never before are fields from artificial intelligence, to autonomy, battery power and aerodynamics.

The Mars 2020 rover is going to travel with a helicopter (Page 63) in keeping with the trend toward novel applications for vertical takeoff and landing craft. This helicopter will have co-axial, counterotating rotors, a concept that U.S. troops could someday rely on to fly at fixed-wing speeds, depending of course on how things go with the Sikorsky-Boeing SB-1 Defiant. Also worth noting: The Mars helicopter idea did not just suddenly pop up. The effort was started in 2013 as a technology development project at the NASA-funded Jet Propulsion Laboratory.

So, here's a suggestion: Look through this issue. Pick one technology or project that you think might go somewhere. Jot it down. Put it into a time capsule and open it in five years. Maybe you'll predict the urban-mobility winner, the next Mars helicopter mission or the next Starman. ★



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AIAA CONGRESSIONAL VISITS DAY

WEDNESDAY, 20 MARCH 2019

Advocate for Aerospace on Capitol Hill

Every year, AIAA members—engineers, scientists, researchers, students, educators, and technology executives—travel to Washington, DC, for a day of advocacy and awareness with national decision makers. Spend a day meeting with new and established congressional members and their staff.

Your participation, enthusiasm, and passion remind our lawmakers that aerospace is a key component of an economically strong and secure nation. If you are interested in the future of your profession, the advancement of technology, the furthering of scientific research, and the strengthening of our nation's security, this event is for you!

Travel subsidies are available

"I enjoy the fact that CVD connects generations of enthusiastic aerospace professionals. For one day they all bring a single voice to the Hill, informing and compelling Congress to support one of our most vital national interests."

KEVIN SIMMONS, Science Educator, The Weiss School (Florida) Founder, BLUECUBE Aerospace

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AIAA
SHAPING THE FUTURE OF AEROSPACE

Providing Value to All AIAA Members

By John S. Langford, AIAA President

It's no secret that AIAA, along with other associations and societies, is facing issues with maintaining and building our membership base. To reverse the steady decline in AIAA membership, we need to focus relentlessly on the value proposition to our membership, and then on getting the word out about that value.

AIAA has long been the largest and most influential **technical** society for the aerospace industry. But what AIAA should be is the **professional** society for the aerospace *community*, encompassing everyone needed to design, build, and fly aircraft and spacecraft. That certainly means engineers, but also managers, designers, fabricators, business and technology professionals, and communications, marketing, and legal experts—just to name a few.

We also must provide value to the organizations for which our members work. AIAA counts nearly 100 corporate members, but that number should be higher. As a CEO and an engineer, I am keenly aware of the value AIAA provides my company and the industry. Unfortunately, many leaders are not. We need to amplify our message to executives and management—that AIAA provides incredible opportunities for talent development through our myriad committees, sections, and student branches, as well as talent acquisition via the students and professionals who attend AIAA forums and events.

For the past year, the AIAA Board of Trustees and I have been working with representatives of key corporate members to develop a set of recommendations that can help guide us. As a result of these conversations, I wanted to share some of my key takeaways:

- **Talent acquisition and talent development are the hallmarks of AIAA's value to our corporate members.** Recruiting, developing, and retaining the world's most skilled and motivated workforce is a priority for every company. AIAA supports the aerospace workforce of today and tomorrow with networking opportunities through section activities, AIAA forums, technical and integration and outreach committees, "Meet the Employer" events, the Diversity Scholars Program, and many others.
- **Senior leadership participation is key.** Senior leaders lead by example. Being an active and visible participant in AIAA programs and activities sends a clear message to employees and the industry that professional workforce development is an important goal. AIAA in return recognizes and embraces this participation, including through our member advancement program and honors and awards.
- **Designate clear organizational points of contact.** Each organization should designate a clear point of contact empowered to speak for that organization—an AIAA ambassador if you will. AIAA leadership will meet regularly with organizational points of contact. Organizations that have implemented this strategy have reported greater information sharing, improved member communication, and progress toward defining and growing value to individual and corporate members.
- **Companies could "sponsor" AIAA membership for young professionals.** Studies have shown that the first five years are the most critical phase of an engineer's career. AIAA has a strong cadre of student branches, which draws many people into AIAA, but that membership drops dramatically once people join the aerospace workforce. Many young professionals—even those who were student members—tell us that with all their other life expenses, AIAA dues don't make the budget. AIAA has reduced dues for student-to-professional transition but sometimes even that is too much. So, what if organizations paid for AIAA membership for each of their new aerospace-related hires for the first five years of their career? It would keep these professionals in AIAA and expose them to all the Institute has to offer. I think it could be a game changer.
- **Set an overall membership target for organizations.** Today, most of our large corporate members have well under five percent of their engineering workforce enrolled as AIAA members. I believe we should target something closer to 10–20 percent of each corporate member's engineering workforce belonging to AIAA by the end of 2020.
- **Encourage young professionals (YPs) to join technical and integration and outreach committees.** Once someone joins AIAA we need them to get involved. Active participation of YPs in technical committees (TC) and integration and outreach committees (IOC) is essential for the long-term relevance and viability of AIAA, and I encourage all employers to support this. AIAA has recently removed numerical limits on the number of participants in any TC or IOC partly because we found that these limits served to discourage young professionals.

At AIAA, we are working to review and improve our programs and our membership structure to meet the needs of the aerospace industry and our members—individual and corporate. AIAA staff and volunteer leaders are actively engaged in making AIAA THE professional society for the aerospace community. Please contact Dan Dumbacher at Daniel.Dumbacher@aiaa.org and me at jslangford@aiaa.org with **your** ideas, comments, and feedback. ★

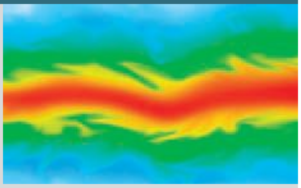
Do you have a puzzler to suggest? Email us at **aeropuzzler@aiaa.org**

Paper airplanes and lift

Q A student shows up at his Airfoils 101 class without having completed his summer reading. The professor, having an eye for slackers, asks him how a wing generates lift. "Well, it's all about the curved upper surface," the student says, noticing the professor pick up a piece of paper and start to fold it. The student continues: "Air molecules flowing over the top travel faster, which under Bernoulli's equation creates ..." Just then a paper airplane lands on his desk. **What point was the professor making with this paper airplane?**

FROM THE NOVEMBER ISSUE

NOISY AIRFOIL



Q. No one guessed correctly that rain caused the roof rack of a new SUV to hum. We asked Anupam Sharma, an aeroacoustics researcher at Iowa State University, to explain how rain could cause the noise:

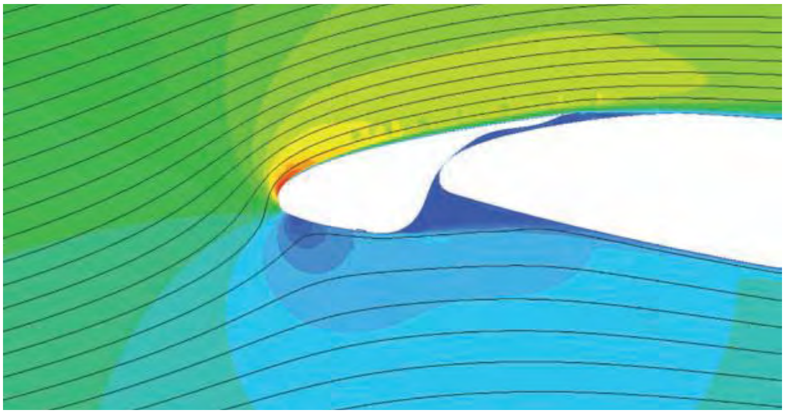
A. "This sounds like a possible aeroelastic problem, similar to what is observed in inclined cables in wind and rain. The phenomenon is called rain wind induced vibration, which arises because of an instability caused by an apparent change in the cross-section of the cable (the crossbars in this case) because of water rivulets. The crossbar becomes asymmetric because of the rainwater on its upper surface. This cross-sectional asymmetry causes the wind to excite the crossbar and makes it gallop (vibrate). This vibration is transferred mechanically to the roof of the SUV, which acts as a soundboard and produces the hum. The criterion for galloping was first proposed by J.P. Den Hartog [a mechanical engineering professor at Harvard and later MIT] in the 1930s when he observed iced power conductors vibrate in the wind."

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

Shape memory materials begin to take shape

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.



Texas A&M University

▲ **Velocity contours** and streamlines around a retracting leading-edge slat treated with the NASA/Texas A&M shape memory alloy "slat cove filler" as computed from full fluid-structure interaction analysis. When deployed, the novel device fills the volume behind the slat, reducing local turbulence and radiated noise; the slat cove filler then deforms as needed to allow full retraction of the slat.

Around the world, researchers are studying both active materials and the structures that use them. Regarding materials developments, a team from the Harbin Institute of Technology first showed in January that a new shape memory polymer composite could be additively manufactured in such a manner that resulting components exhibit remotely actuated self-expandable behavior under an alternating magnetic field.

Also, **researchers at Arizona State University, funded by the U.S. Army, this year advanced the development of novel "mechanophore" materials that change color under mechanical loading to detect damage in aerospace composites**. Early this year, this team conducted demonstrations of damage detection in composite specimens undergoing fatigue loading using the mechanophore materials, and damage was indicated, as expected.

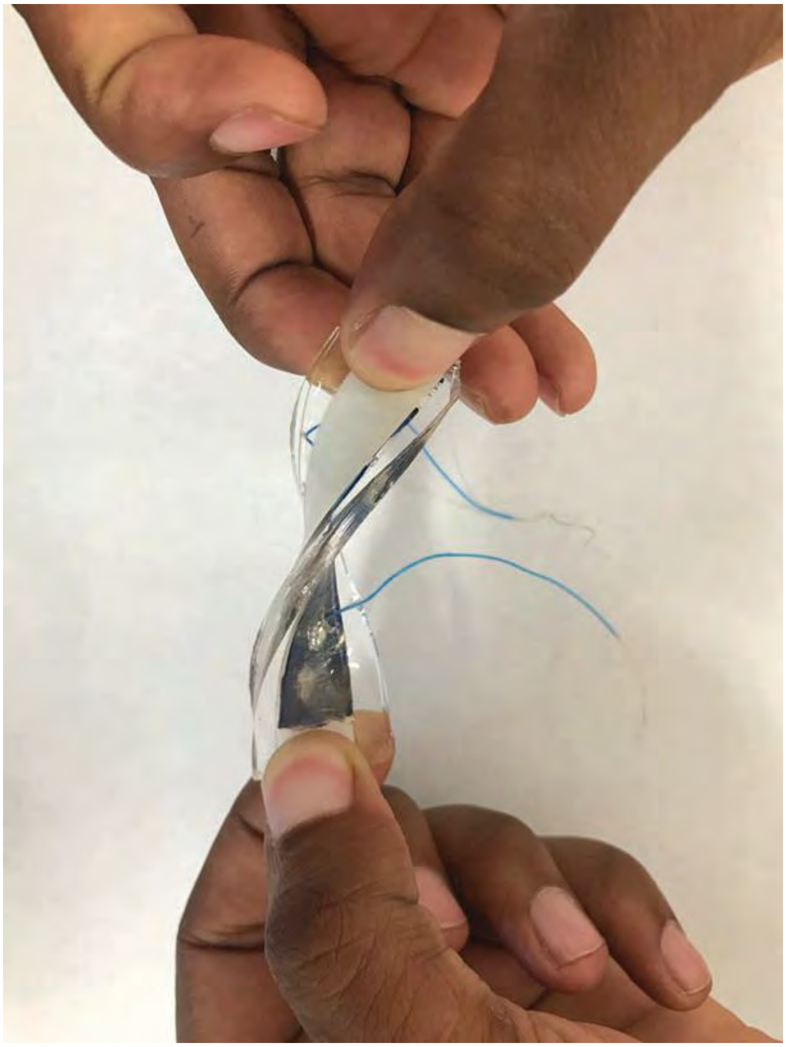
The U.S. Navy this year supported researchers at the University of Central Florida in developing an approach for detuning resonance in structures using electro-mechanically coupled materials. This approach was experimentally validated on a bladed disk in late 2018. This research will reduce maintenance, repair and overhaul costs associated with blade high-cycle fatigue and failure by effectively reducing harmful vibrations across multiple vibration modes.

U.S. Air Force researchers have developed a suite of materials called liquid crystal elastomers that can be configured to generate out-of-plane surface topography upon actuation from a flat state. Complex material patterns resulting in advantageous surface topological features have been simulated with high fidelity models and were experimentally characterized under realistic pressure loads during wind tunnel tests completed in March. Such features can act as vortex generators and distributed roughness elements, enabling decreased drag and increased stability and control authority across a range of flight conditions.

Enhancing wind tunnel testing of more conventional concepts using active materials, and specifically solid state, rugged, and highly compact shape memory alloy, or SMA, components, was also a focus in 2018. Traditional wind tunnel testing involves changing out numerous fixed parts, but remotely controlled wind tunnel models replace these nearly rigid parts with moving, controllable alternatives, enabling increased productivity and improved data quality, and reducing the cost of wind tunnel testing. This year, a team comprised of Boeing, the European Transonic Windtunnel, NASA's Langley Research Center in Virginia, and Deharde Maschinenbau of Germany developed and tested numerous such SMA-based remote controlled components in cryogenic high-speed wind tunnels to validate this technology. Testing will continue into 2019.

NASA also worked with Texas A&M University researchers this year to solve problems regarding both subsonic and supersonic aircraft noise. In phases of low-speed flight, the deployment of control surfaces can lead to substantial noise. The NASA/Texas A&M team developed an adaptive structures/SMA solution to altering air flow around these surfaces. Collaborating also with the University of Bristol, this team showed in March and April for the first time that both composite and SMA solutions could be feasible.

Regarding supersonic flight, although aircraft such as the NASA/Lockheed Martin X-59 QueSST — for quiet supersonic technology — can be designed to quiet the sonic boom perceived at the ground under certain atmospheric conditions, Texas A&M and Utah State researchers, supported by NASA, showed for the first time in June that the strength of this boom will vary by more than 10 decibels across the country on a given day due to local changes in the atmospheric profile. Specific morphing concepts will be developed in 2019 to soften booms regardless of changing conditions. The feasibility of such large-scale morphing was proved during separate experiments by NASA and Boeing in June, which showed that large SMA torque-tube actuators capable of 564 newton meters could move a full-sized wing section of an F/A-18 Hornet under flight loads. This milestone for largest aircraft-tested SMA actuator was then scheduled to be surpassed in late 2018 by an actuator rated at 2,260 newton meters.★



New Mexico Tech

Modeling takes the lead in driving materials research for the future

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.

▲ **Sensing strain:** When twisted and deformed, an MLO (mechano-luminescence-optoelectronic) composite generates measurable direct current. New Mexico Tech has conducted research on MLO technology for unmanned aircraft.

In the realm of unmanned aircraft, long-duration mission profiles and increased reliability this year motivated development of innovative multifunctional mechano-luminescence-optoelectronic, MLO, composites to be integrated into next-generation unmanned aircraft at New Mexico Tech in collaboration with NASA's Armstrong Flight Research Center in California. MLO composites are composed of two functional constituents, such as mechano-luminescent copper-doped zinc sulfide-based elastomeric composites and mechano-optoelectronic poly (3-hexylthiophene)-based self-sensing thin films. MLO composites can be integrated with fiber-reinforced polymer composites to create autonomous composites, AutoCom, that exhibit a self-powered strain sensing capability that enables detection of fatigue damage and a mechanical-radiant-electrical energy harvesting capability that provides supplemental energy to the aircraft.

Researchers at the University of Alabama in January quantified efficiency of self-healing composites in Mode-1, the term for testing double-cantilever beams of composite. They determined the interlaminar fracture toughness using the ASTM-D5528-13 standard for such double-cantilever beam, or DCB, tests. Seven separate healing cycles with thermoplastic healants were performed to assess healing repeatability with maximum healing efficiencies of 73 percent, and 63 percent achieved after the seventh healing cycle for DCB specimens with and without shape memory polymers, respectively. The importance of this "close then heal mechanism" investigation of dispersed shape memory polymers along the delamination plane was demonstrated.

In March, NASA published its much anticipated technical report, "Vision 2040: A Roadmap for Integrated, Multiscale Modeling and Simulation of Materials and Systems." Publication of this vision was significant, because materials scientists in the past separated modeling from experimentation. The vision draws these two functions together, so that in the future a simulation can span across all modeling scales to include the structure. The vision was developed under NASA's Transformational Tools and Technology Project to define the potential 25-year future state required for integrated multiscale modeling of materials and systems to accelerate the pace and reduce the expense of innovation in future aerospace and aeronautical systems. Such an interdisciplinary effort with multiple stakeholders from various backgrounds coming together has profound implications for any engineering community optimization of the development of load-bearing structures.

This road map is a community consensus document and is a result of input from about 450 professionals. This input was obtained through a series of workshops organized by AIAA, the International Association for the Engineering Modelling, Analysis and Simulation Community (also known as NAFEMS) and the Minerals, Metals and Materials Society. Also, a communitywide survey was conducted, and a variety of expert panels were convened. This road map is intended to provide strategic guidance to both public and private research and development decision-makers to achieve the proposed vision for the year 2040. ★

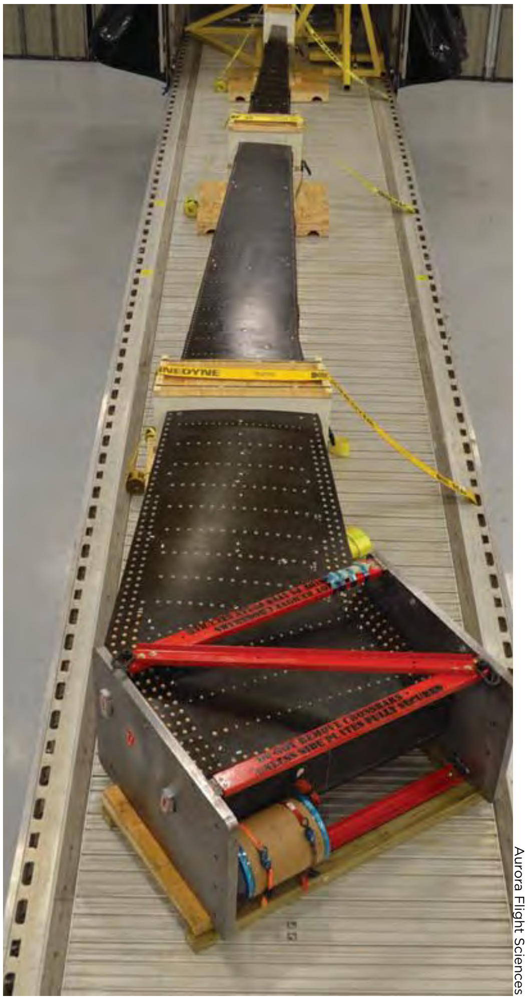
New computing tools, international collaboration spell design progress

BY DOUGLAS L. ALLAIRE AND KAREN E. WILLCOX

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.

OpenMDAO is an open-source high-performance computing platform for systems analysis and multidisciplinary optimization. In June, the optimal control library Dymos was released and used to optimize electric aircraft trajectories with acoustic and thermal constraints. Dymos is built on OpenMDAO Version 2, which NASA released late in 2017. Also in June, a collaboration between NASA and the University of Michigan used OpenMDAO to develop the first fully coupled aeropropulsive MDO for a boundary layer ingestion propulsion system.

In January, Mississippi State University released the Multidisciplinary-design Adaptation and Sensitivity Toolkit multiphysics, an MDO toolkit that supports coupled conduction, nonlinear structural, fluid flow, and flutter analyses, and sensitivity with respect to sizing and level set topology parameters. In July, University of California, San Diego published open-source level set topology optimization software. This new software routinely runs 10 million element models by adapting and tailoring the level set method, making design for additive manufacturing immediately accessible.



Aurora Flight Sciences

Aurora Flight Sciences' 27 percent scale test article of the optimized tow-steered wingbox was tested in October at NASA's Armstrong Research Center in California.

In January, NASA's Goddard Space Flight Center in Maryland developed an MDO framework for design under uncertainty and model validation of the James Webb Space Telescope. The European-funded H2020 project launched the AGILE Academy, AGILE being short for Aircraft Third Generation MDO for Innovative Collaboration of Heterogeneous teams of Experts.The academy hosts more than 40 students from 15 institutions across the world from February to July. In January, the University of Illinois developed new system architecture design methods that use machine learning with data from enumeration and design optimization, with application to aircraft cooling systems and power electronics. In March, the University of Michigan performed the high-fidelity aerostructural design optimization of a tow-steered composite high aspect ratio wing. A third scale model of the optimized wing box was built by Aurora Flight Sciences using an automatic fiber placement machine and will undergo ground vibration testing at NASA. In June, Embraer and Instituto Tecnológico de Aeronáutica in Brazil developed new methods for optimization under uncertainty and demonstrated how upfront reduction of uncertainties improves design competitiveness without sacrificing reliability.

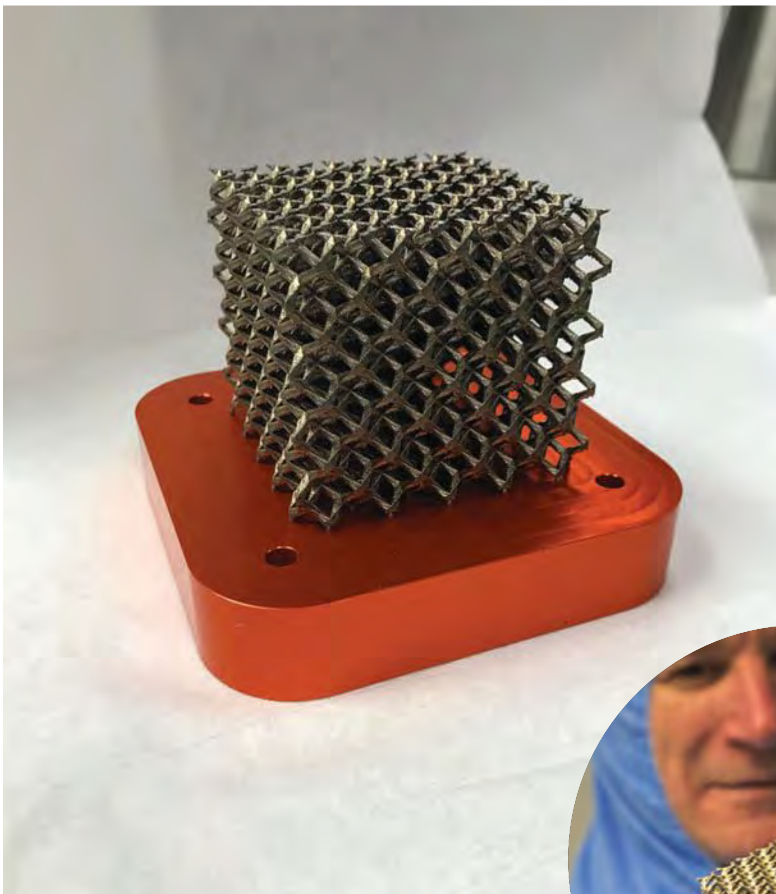
M3 is a U.S. Air Force Multidisciplinary University Research Initiative developing new methods to manage multiple information sources in MDO. In July, the M3 team released BOCS, a toolbox for Bayesian Optimization of Combinatorial Structures, and in November the team released a multifidelity toolbox for evaluating stability boundaries, CLoVER, short for Contour Location Via Entropy Reduction.

Boeing completed the Air Force Research Laboratory's Optimized Integrated Multidisciplinary Systems program in October. OPTIMUS showed the importance of including power and thermal subsystems during conceptual-level design, not only for understanding the internal subsystems themselves, but also for their pronounced effects on the outer mold line and shape of the air vehicle. This program also pushed the state-of-the-art in distributed collaborative design that was demonstrated between Boeing and GE. ★

Researchers aid development of AI, additive manufacturing

BY ANDREW C. OLLIKAINEN

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



Southwest Research Institute

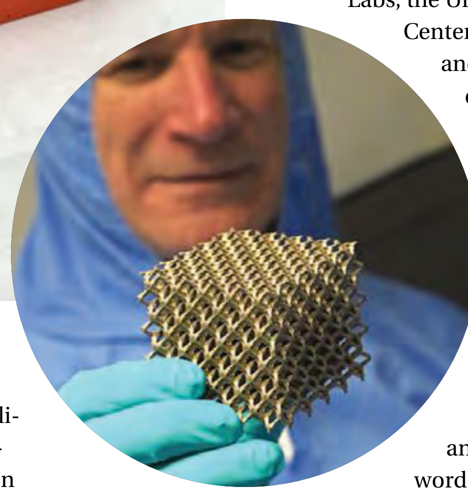
▲ **Additive manufacturing** enables the creation of lightweight parts, like this lattice structure produced at Southwest Research Institute in Texas. The variation in geometry and the uncertainty in material properties must be considered to qualify these optimized designs.

From deriving material allowables to design optimization to reliability-based fleet management to service life extension programs, the field of non-deterministic approaches directly impacts how risk is managed and airworthiness is assured and maintained. This field of applied mathematics deals with uncertainty with a foundation of statistics and probability. Researchers develop the methods and techniques that enable the aerospace enterprise to, for instance, identify and quantify uncertainty in all stages of a vehicle's life cycle.

Many artificial intelligence and machine learning programs rely heavily on techniques common to non-deterministic approaches. AI is already ubiquitous when discussing autonomy and AI is now being applied to "classical" NDA such as the optimization of vehicle design, and the fusion of data input from multiple sources. More progress on this front was made this year.

In January, **a team of researchers from the Massachusetts Institute of Technology, Naval Postgraduate School and Brown University presented the application of statistical learning in the design optimization of a specialized hydrofoil**. In July, DARPA issued a program announcement for a streamlined contracting vehicle for basic and applied research in AI. In August, the first opportunity under the Artificial Intelligence Exploration program was listed for automated scientific knowledge extraction.

Accounting for uncertainty in multidisciplinary design optimization and risk analysis involves a very large number of iterations. As the number of variables in the system increases, so too does the computational resources needed to solve these problems. Over the course of the year, **researchers from government, industry and academia advanced methods to increase the efficiency of solving higher-order problems**. Specifically, researchers undertook this kind of NDA work at the U.S. Air Force Research Laboratory, Army Research Lab, Sandia National Labs, the United Technologies Research Center, GE Global Research Center, and at several universities. Several projects benefited from the continuing support of DARPA's Defense Sciences Office through the Enabling Quantification of Uncertainty in Physical Systems program. This program aims to advance NDA for large-scale, complex systems.



Additive manufacturing and 3D printing were buzzwords in the industry in 2018. In order to benefit from all the possible opportunities these technologies afford, it must be proven that parts made by these processes are safe to fly. Understanding the impact on structural risk requires quantifying the uncertainty associated with how variability in manufacturing parameters impact scatter in mechanical properties. Southwest Research Institute, University of Michigan, Ohio State University, University of Tennessee, Texas A&M, Vanderbilt University and University of Wisconsin worked to improve our understanding of the uncertainties involved in material variability and how to model them. ★

Designing the world's largest wind turbine

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.

▶ **A high aspect ratio wing model** undergoes tests in the low speed wind tunnel at Airbus Filton in the United Kingdom.

Airbus

This was another fruitful year for the structural dynamics discipline across industry, national laboratories and academia.

In the field of energy generation, **researchers at the University of Texas at Dallas in April completed a design study for what would be the world's largest wind turbine**. The UT Dallas team is investigating rotor blade designs beyond 150 meters in length for SUMR, the Segmented Ultralight Morphing Rotor. The largest blades today are roughly 90 meters. Longer blades would increase energy capture and dramatically reduce the cost of generating electricity. The ultimate goal is to develop a 50-megawatt wind turbine with blades of lengths over 200 meters. The SUMR project team is developing and integrating technologies to enable extreme-scale wind turbine rotors, including advanced controls and aerodynamics, hinge morphing, and novel structural design. The UT Dallas team is focused on lightweight structural design with an emphasis on addressing critical requirements for extreme loads, rotor dynamics and aeroelastic stability, which are of growing importance and a significant challenge for these extreme-scale rotors.

Turning to aircraft wing design, in July and August **the University of Bristol and Airbus UK performed low-speed wind tunnel tests on a very flexible 2.4-meter-long model wing**. The tests were part of the three-year Agile Wing Integration project funded by the United Kingdom's Aerospace Technology Institute. The objective of the tests was to validate nonlinear aeroelastic predictions of the static and dynamic behavior of high aspect ratio wings by making detailed simultaneous structural and aerodynamic measurements. Static tests included measurement of deflections and resulting lift, drag and pressure distributions for different speeds and root angle of attack. Further tests have characterized the dynamic behavior, including limit cycle oscillations occurring due to geometric nonlinearities and stall.

In the area of computational tools, researchers at **Sandia National Laboratories performed a fatigue margin assessment on a Sandia system using their newly developed parallel python toolbox, SIESTA**. The finite element model had 12 million degrees of freedom and 3.5 million elements, and had several structural aspects, including fasteners. A normal mechanical environment lifetime was simulated, which consisted of random vibration and shock events. The analyses required several terabytes of data storage for the full system assessment. SIESTA predicts high cycle fatigue in large system models in the time and frequency domains and has been verified against test data. Credibility was established by comparing predictions against experimental work, including a simple tension test, a narrow-band random vibration, and a wideband random vibration.

In 2018, Sierra Nevada Corp. advanced toward a final detailed design in developing its Dream Chaser spacecraft under NASA's Commercial Resupply Services 2 contract to transport cargo to and from the International Space Station. Reusable spacecraft like the Dream Chaser are subject to significant cumulative thermal and structural loads over their design life. As such, the Sierra Nevada team needed to perform detailed structural fatigue assessments to ensure the vehicle's safety. To overcome the computational challenges associated with performing time-domain fatigue analysis of Dream Chaser's composite structures, Sierra Nevada partnered with ATA Engineering Inc. ATA delivered software tools in March capable of efficiently generating and combining time-domain loads for various stages of flight in a parallelized framework. ATA's software tool provides properly phased dynamic stress results under combined loading for fatigue analysis of composite structures, as well as cycle-count histograms via rainflow counting of principal stress time histories for assessment of isotropic components. ★

Multiple structures take shape

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.


NASA

▶ **A test version of the** intertank for NASA's Space Launch System rocket is readied for structural tests at NASA's Marshall Space Flight Center in Alabama. The test article was pushed, pulled and bent this year to ensure the design can withstand launch and ascent. The tank is structurally identical to the one that will connect the core stage's fuel tanks.

Mississippi State University's ongoing delamination studies with the U.S. Air Force Research Lab, or AFRL, continued this year with the primary objective to increase composite delamination resistance by optimizing stitching parameters for the university's Marvin Dow Advanced Composites Institute's unique 3D stitching capabilities. Experimental setups designed to load samples under idealized delamination modes were used to investigate the ability to capture delamination front shapes and locations. To date, measured strains compare favorably with finite element results.

Under an AFRL contract that will continue into 2019, Boeing investigated two different progressive damage and failure analyses, developed by the University of Texas–Arlington, to accurately predict damage initiation and progression in military aircraft composite components by comparing analytical and experimental results. Boeing's fabricated hat-stiffened composite skin replicates mechanically fastened aluminum ribs. AFRL tested two configurations: skins under constant compression with rib pull-off in static and fatigue loadings, and rib pull-off performed in 4-point bend without end loading in static and fatigue modes. Good correlation was seen between predictions and test results, improving the Air Force's ability to safely extend service longevity.

Engineers at NASA's Marshall Space Flight Center in Alabama installed structural test hardware for NASA's deep space rocket, the Space Launch System, and began testing. The test hardware is structurally identical to the intertank flight hardware that connects the core stage's two fuel tanks, serves as the upper-connection point for two solid rocket boosters, and houses critical electronics. The test facility's cranes and design features duplicate extreme spaceflight conditions. The SLS hardware is pushed, pulled and bent with thousands of kilonewtons to ensure it can withstand launch and ascent forces.

In aircraft modeling, engineers at the University of Pisa and San Diego State University created an automatic finite element model generator to produce structural models of boxed-wing aircraft, known as PrandtlPlanes. The work was performed under a European Commission-funded project called PARSIFAL, short for PrandtlPlane Architecture for Sustainable Improvement of Future Airplanes. The aim is to demonstrate how the adoption of boxed-wing aircraft can bring significant improvements to air transportation.

In February, a biologist at Carleton University in Ottawa, Canada, while recording Nessus sphinx hawkmoth caterpillars emitting whistle-like sounds, could not determine the mechanism behind the sound. Subsequently, Carlton aerospace faculty performed aeroelastic studies that included plate and shell models combined with internal fluid flow to determine this mechanism. The sound was found to be generated by flow exiting the caterpillar's stomach into its mouth, which acts like a resonator. This is the first time that a fluid-structure interaction has been identified as a sound generation mechanism in insect acoustics.

Meanwhile, the Air Force Institute of Technology worked on a range of Air Force engineering structural research topics, including continuing research on the internal-vacuum lighter-than-air vehicle (both NASA and the Air Force have shown interest), impact welding at velocities greater than 700 meters per second, hybrid composite structures, laser shock peening, sensor design, and heat flow around a sphere.

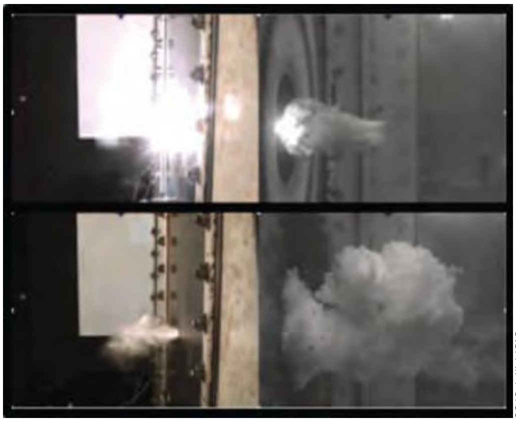
NASA's Johnson Space Center in Texas and Langley Research Center in Virginia are examining the integrity of inflatable airlock structures for use on future deep space exploration missions and the lunar orbiting gateway. This year's development work focused on an internal secondary structure, rigidizeable handrails, and soft opening hatches for quick ingress and egress and will continue into 2019.

As part of NASA's Aeronautics Research Mission Directorate Convergent Aeronautics Solutions program, Langley and NASA's Ames Research Center in California and Glenn Research Center in Ohio in April completed the Multifunctional Structures for High Energy Lightweight Load-bearing Storage, or M-SHELLS, project, demonstrating production feasibility of multifunctional honeycomb sandwich panels where the core serves as a battery. Test results demonstrated that cores can sustain service level loads without any noticeable multifunctional performance degradation. System level studies of M-SHELLS cores in a 2030 single-aisle hybrid-electric transport aircraft indicate up to 11 percent potential mass savings vs. standard cores combined with separate batteries. ★

U.S. Air Force tests steel fragments against aluminum, assesses penetration of fuel tanks

BY AMEER G. MIKHAIL AND ALEX G. KURTZ

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



U.S. Air Force

▶ **A high-speed camera** photographed a hydrodynamic ram event, HRAM, this year to assess the vulnerability of fuel tanks to penetrating threats. The impact occurs from left to right. The resulting bubble inside the tank can be seen on the right side. The resulting fluid spurt goes out of the impact hole on the left. The research was conducted at Wright-Patterson Air Force Base, Ohio.

For characterization of aircraft vulnerability to steel fragments' impact on aircraft aluminum structure, the resulting entry and exit flash strengths and flash durations need to be measured. The U.S. Air Force from January to July conducted impact tests at Wright-Patterson Air Force Base in Ohio to acquire impact flash data. This data will aid in developing and validating models to predict the duration of front-face and back-face flash from steel fragments impacting aluminum target plate arrays. The data also will help in developing algorithms to predict the duration of front-face and back-face flash from steel fragments. The tests were performed using high-speed cameras and experimental laser imaging capture techniques from the Air Force Institute of Technology. The project is being executed within the structure of an integrated product team in support of the Next Generation Fire Model. The objective of the project is to generate data, perform shock physics on modeling and simulation, and develop and implement algorithms for fragment flash for accurate predictions of aircraft vulnerability to fragment threats.

The Air Force this year continued its HRAM, for Hydrodynamic Ram, Spurt Model Development and Validation program for fuel tank vulnerability from penetrating munitions by performing Phase 2 planning in April, followed by testing in August and September, building on its effort and data obtained in fiscal 2017 of Phase 1. The objective of the program is to develop an understanding of the fundamental physics associated with ballistically induced, hydrodynamic fuel spurts through physics-based modeling, supported with test data and statistical analyses. The program will ultimately lead to a fast running tool for predicting spurt timing within fuel tank vulnerability assessments. This Phase 2 HRAM testing is using a large fuel tank and pressure transducers designed to be submerged in fluids. A parallel approach is underway using physics-based analysis techniques and test data.

The Air Force continued its fuel tank ullage vapor ignition vulnerability study this year by performing a test series to characterize the vulnerability to simulated fragment induced fuel tank ullage ignition. Ullage conditions and fuel temperatures were based on flight scenarios, altitudes and combat sortie simulations. The test series evaluated ullage ignition characteristics within a simulated fuel tank utilizing various fuel conditions, igniter locations, fuel heights/levels, geometric conditions via three tanks, and several internal pressures. Three fuel tank sizes, including 2,100 liter and 3,790 liter capacity (1,000 and 550 gallons), were tested during January to July and filled with Jet A fuel. To simulate a threat encounter at high altitudes, the fixtures were tested under low vacuum conditions, which was the first ever test series within the survivability community. Tests were able to be conducted under pressure conditions down to 20.7 kilopascal (3 pounds per square inch absolute) from an atmospheric pressure of 98.6 kilopascal (14.3 PSIA). The test series also investigated a sequence of vented ullage ignition tests conducted within the fuel tank simulator. Over 300 tests have been conducted to date. Data are being used for aircraft fuel tank design and are being transitioned into the Next Generation Fire Prediction Model.

On the civilian aviation side, **the engine fan blade containment accident in April on a Southwest Airline flight exemplified the sound design intent for containment but also the inability to prevent additional separated parts from damaging the fuselage**. The GE-Safran engine has 24 metallic (titanium) blades one of which separated at the root, due to metal fatigue. Blade separation is rare, occurring about three to four times a year worldwide. The Southwest blade, though contained, caused impact damage to the inlet and fan cowls, causing large pieces to separate and cause damage to the wing and fuselage. One piece hit and shattered a passenger window causing a fatal injury. The plane landed safely in Philadelphia with one engine. This is an example of aircraft design for survivability (landing with one engine), but reflects still-needed efforts in preventing engine secondary parts from separation due to blade impact. ★

Systems engineers draw lessons from artistry

BY JEFF NEWCAMP

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

It is not uncommon for the lifecycle of complex engineered systems to span decades. This presents a problem because systems engineering, or SE, at its core is a set of tools to design and manage these complex systems over their respective lifecycles. Currently, testing SE tools quickly requires modeling that can simulate the lifecycle of systems.

In searching for a more innovative method to evaluate SE tools, researchers turned to artistic fields in 2018 because of their analogous natures. According to Bryan Mesmer, an assistant professor at the University of Alabama in Huntsville, the arts provide "a short time span, wide availability and similar human interactions" to complex systems. Researchers can compare the lifecycle of a complex engineered system to the creation of an oil painting or symphony, for example.

The creative process for an artist writing a symphony involves many of the hallmarks known in complex systems: networks, human capital, schedules and more. The obvious differences between artistic projects and engineering projects are their subject matter and their time scales. However, imagine if the techniques, processes and lessons can be generalized from the arts and applied to engineering. In 2018 researchers tested new SE tools on arts projects to increase maturity and confidence prior to using them with engineered systems.

▼ Understanding the functioning of an orchestra could help systems engineers be more effective. Orchestras are complex, low-cost proxies that are hierarchical, involve multiple disciplines and have a lifecycle.

U.S. Air Force

"You can refine a new process over five or 10 lifecycles when you apply the process to an art project," said Mesmer, "whereas it is difficult to test a new theory over the lifecycle of a new aircraft."

This year, there was a marked increase in the field's focus on the arts as a proxy for engineered systems. "We really think this niche in systems engineering will develop into a viable incubator for lifecycle thinking," said Alejandro Salado, an assistant professor of systems engineering at Virginia Tech. Salado's early 2018 research analyzed master painter techniques that could be transferred into use by systems architects to reduce system complexity. Virginia Tech led this field's innovation with an SE course that is taught like a studio art class. The course started in August at the beginning of the fall term.

Systems Engineering experts posed a key question in 2018: As systems grow increasingly more complex, will SE ideas grow in complexity also, or will a new approach gain momentum? For those studying the link to the arts, it will be the simplicity and creativity from the arts that aids decision-makers when solving SE problems.

In April, researchers on a project at the University of Alabama in Huntsville took a novel approach to improve stakeholder preference communications. **The research team analyzed effective storytelling elements that could be adopted by engineering managers to better communicate stakeholder preferences.** The research found that backstory structure in case studies does not significantly affect reader performance but does impact case study length. **Another project this year focused on the ways in which filmmaking techniques can improve how systems engineers view and illustrate models through model based systems engineering.**

An example from theater productions compares the milestones known in SE to those that are accomplished in theater. Think about everything engineers can learn from surrogates. The system requirements review becomes an apt stand-in for pre-production steps of casting and script refinement in a theater production. Similarly the preliminary design review and the critical design review mimic a play's early rehearsing and later dress rehearsals. Perhaps the SE field can learn from the mistakes a theater production makes and apply those lessons to a complex engineered system.

"Solving systems engineering challenges through the lens of the arts is such a compellingly simple approach," said Mesmer, "that it just might work." He added, "The past year has set us off in a new direction." ★

Predicting, reducing noise from supersonic jets and unmanned aircraft

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.

Virginia Tech

▲ **Virginia Tech opened** the tallest netted drone park in the United States for research in small unmanned aircraft operations.

The rollout of unmanned air vehicles into daily life is underway, and the aeroacoustics community is working to ensure that noise does not become a barrier to developments for unmanned air systems, or UAS. In April, Virginia Tech opened the tallest netted drone park in the United States. At 85-feet tall, 300-feet long and 120-feet wide, the park will be used for research in small UAS operations. In August, Uber Elevate, U.S. Army Research Labs and the University of Texas at Austin launched a collaborative effort to explore the efficiency and noise signature of stacked co-rotating rotors for vehicle concepts at Uber Air, Uber's proposed urban aviation ride-share network.

The International Civil Aviation Organization, or ICAO, anticipates the certification of a new supersonic airplane for overland flight in the 2020-2025 timeframe. This year, NASA conducted independent noise predictions using its Aircraft Noise Prediction Program code to support ICAO's Working Group 1 in **evaluating landing/takeoff noise for a supersonic transport conceptual aircraft**. The studies included advanced takeoff procedures to determine potential benefits for reducing community noise. In May, NASA completed a three-year effort to assess sonic booms in atmospheric turbulence, or SonicBAT, involving flight experiments at NASA's Armstrong Flight Research Center in California and the Kennedy Space Center in Florida. The data were used to develop prediction algorithms for the loudness of sonic booms from modern low-boom aircraft designs. The SonicBAT team, led by Wyle Laboratories, included Pennsylvania State University, Lockheed Martin, Gulfstream Aerospace, Boeing, Eagle Aeronautics and the France-based Fluid Mechanics and Acoustics Laboratory.

Jet noise reduction efforts focused on **the application of noise reduction strategies to high-performance or future complex jet propulsion**. In March, the Discovery Channel's Daily Planet teamed with the University of Mississippi, University of Texas at Austin and CRAFT Tech Inc. to film a documentary on jet noise as part of an ongoing campaign to tell the public about the achievements being made to reduce supersonic jet noise for tactical aircraft. In April, the Office of Naval Research and Naval Air Systems Command co-hosted a workshop on turbulence, wavepackets and jet noise at the California Institute of Technology. The workshop signified the community's maturation of a number of theoretical tools such as resolvent analysis, adjoint-based sensitivity, and advanced source localization techniques. The workshop sought to define a path toward enhanced passive and active noise reduction by fully utilizing powerful large-eddy simulations and state-of-the-art laboratory diagnostics. In May, researchers from Syracuse University, Ohio State University and Spectral Energies LLC, with support from NASA and the Air Force Office of Scientific Research, **completed the simulation, measurement and validation of a complementary computational and experimental data set for a supersonic multistream single-expansion ramp nozzle flow**. The measurements and simulation were constructed so that 1-to-1 comparisons could be used to converge higher-order statistical information relevant to the details of jet noise production when a supersonic jet skims over a portion of the fuselage.

NASA prepared for the 2019 launch of the Space Launch System, or SLS, the most powerful rocket NASA has built, and the correct determination of the vibroacoustic environment is key to the success of the mission. In mid-2018, researchers at NASA's Marshall Space Flight Center in Alabama and the University of Texas at Austin completed a series of tests for determining the acoustic geometric attenuation factor for hydrogen vapor cloud explosions, a significant component for a refined estimate of the vibroacoustic loads that form on the launch pad during the SLS liftoff. More testing of this type will continue in 2019. ★

Contributors: *Cliff Brown, Dom Maglieri, Nathan Alexander, Mark Glauser and Charles Tinney*
Editor's note: *Nathan Murray is an employee of the University of Mississippi.*

Researchers measure xenon at low concentrations, demo novel approach to measuring particle velocities

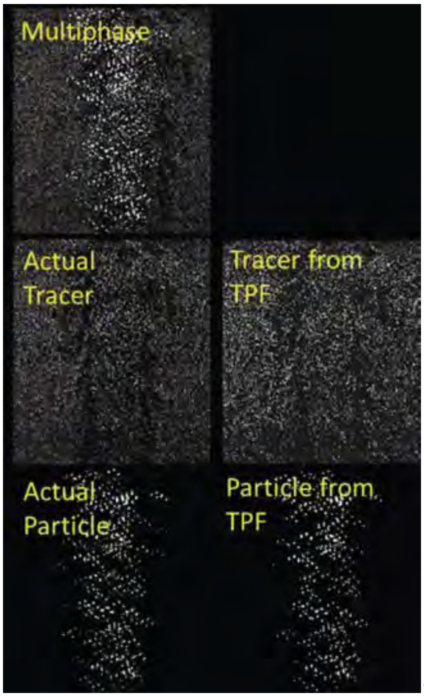
BY THOMAS P. JENKINS AND DAVID H. PLEMMONS

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

In January, researchers with MetroLaser Inc., Colorado State University, Princeton University and Texas A&M University demonstrated two-photon absorption laser-induced fluorescence, or TALIF, to measure concentrations of neutral xenon atoms at very low concentrations. Although the technique dates back to at least 1996, these results represent the first time it has been demonstrated at such low number densities, which are relevant to Hall effect thrusters operating in space. Results showed an improvement in detection limit of three orders of magnitude over previously reported data. TALIF will help designers produce more efficient and longer-lived ion thrusters for applications in space exploration and defense. In September, the U.S. Air Force awarded the MetroLaser-led team follow-on funding to implement the technique on a full-scale Hall effect thruster.

In February, **MetroLaser, in a joint program with Ohio State University, demonstrated a novel technique for measuring gas phase and particle velocities simultaneously by applying particle-size-sensitive image processing techniques prior to particle image velocimetry**. The method enables two-dimensional distributions of gas velocity from small tracer particles by isolating them from larger particles using computational two-parameter filtering of the raw images. Researchers also analyzed the large particles in a similar way, separating them from the small particles to provide simultaneous particle velocities. The researchers then overlaid the resulting gas and particle velocity fields to provide a complete picture of the two-phase flow. The new diagnostic capability could have major benefits in experimental studies of gas-particle momentum exchange with applications in studying multiphase blasts, fuel injection sprays and a wide range of industrial processes.

Engineers and scientists at the Arnold Engineering Development Complex in Tennessee implemented an enhanced measurement capability in the von Karman Gas Dynamics Facility hypersonic wind tunnels B and C. The new technology uses a large-format infrared camera to image surface temperatures of metallic test articles. The test article surface is coated with a material that exhibits near blackbody emissivity over the temperature range of interest. The infrared images from the test article surface are converted to temperature images using the Planck blackbody radiation formula. The temperature images are used to infer boundary layer transition from laminar to turbulent by registering the temperature increase associated with a turbulent boundary layer. Analysis of the temporal evolution of the surface temperature yields heat transfer through the model surface. Local values of heat flux and shear stress on a hypersonic aircraft's surface affect the aircraft's thermal and aerodynamic performance. The infrared imaging techniques implemented at Arnold Engineering Development Complex enable global assessment of these variables over the entire surface of a wind tunnel test article.



Ohio State University

The multiphase flow image at the top is composed of two experimental images, one of tracers and one of particles. The multiphase image was processed to recover nearly these same two images using the two-parameter filtering, or TPF, method, as seen on the right. The images on the right are undoctored images, while those on the left were obtained by processing the combined image.

Near-wall measurements are widely considered one of the major technical challenges for experimental aerodynamics studies, and particle image velocimetry, or PIV, measurements in these regions are particularly difficult. **Professor C.B. Lee and his research group at Peking University developed an image parity exchange, or IPX, technique in 2013 by adding optimal synthetic particles on the solid side for more accurate flow measurements in the near wall regions.** The improved image-preprocessing method expands the traditional window deformation iterative multigrid scheme in PIV image processing. The IPX method was applied this year to investigate the initial growth of flow asymmetries over a slender body at high angles of attack to extract the high-frequency coherent flow structures in hypersonic boundary layers. ★

Editor's note: *Thomas P. Jenkins works at MetroLaser.*

Real-world geometries, wind tunnel tests bring improved results

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.

The CFD Vision 2030 report published in 2014 formed the basis for NASA to perform validation experiments, including some this year, that will enable the accurate prediction of unsteady separated flows. NASA, with an integrated team of computational and experimental researchers, designed a validation experiment to assess the flow at the wing-body juncture, and in May and June finished installing the required model in the 14-by-22-Foot Subsonic Wind Tunnel at NASA's Langley Research Center in Virginia. Using a unique on-board Laser-Doppler Velocimetry system specifically designed for measuring the near-wall juncture region flowfield through windows built into the model, unsteady velocities and velocity moments were measured over the fuselage and wing, and in the separation region. Additional data included steady and unsteady pressures, time-resolved particle image velocimetry, unsteady surface shear stress, optical measurements for model deformation, and infrared thermography to document flow transition characteristics. These data will be available for computational fluid dynamics researchers worldwide for the validation and aid in improving the capability to predict turbulent separated flows.

A finding of the 2018 Sustainable Aviation Symposium in May was that, for electric aircraft, high-torque, low-RPM "many blade" rotors retain high efficiency while limiting both diameter and noise for a given thrust. Such low speed and high torque dovetails with the near-term development of motor-generators specially-tailored thereof.

The year also saw big leaps in the capability to automate numerical grid generation processes and robust solution processes that can produce accurate solutions on such automatically generated grids. Real world geometries such as full helicopter or aircraft have presented challenges for strand overset meshing, but in the last few years, significant advances in robust, automated near-field meshing capabilities in conjunction with overset grid solution strategies that allow for self-intersecting grids have overcome such issues. Researchers at the U.S. Army's Aeroflight Dynamics Directorate at Moffett Field, California, demonstrated simulations on automatically constructed strand meshes — generated in parallel at runtime. This was done on real-world geometries such as the Japan Aerospace Exploration Agency Common Research Model used in June at the AIAA High Lift workshop, the Pressure-Sensitive Paint rotor used in the AIAA Rotor Hover workshop, and a UH-60A aircraft. Accuracy was shown to be comparable to calculations on traditional structured and unstructured meshes. All strand calculations were performed using the Defense Department's High Performance Computing Modernization Program, or HPCMP, CREATETM-AV Helios code, the first widely available production code with support for such strands grids.

Engineers at the U.S. Army Natick Soldier Research Development and Engineering Center in Massachusetts made significant advances in accurately modeling and predicting parachute behavior for Army operations. Working in collaboration with the High Performance Computing Research Centers at the U.S. Air Force Academy, flow field predictions for a C-130J in personnel airdrop configurations have aided safety investigations and informed the design of a new parachute deployment system. Unique to these simulations was the addition of propeller wakes using the fixed-wing software suite HPCMP CREATETM-AV Kestrel. The group also teamed with computational engineers at Georgia Tech to investigate helicopter sling load dynamics. Using Kestrel and its rotorcraft counterpart Helios, this work is providing data for sling load flight certification.

In collaboration with NASA's Jet Propulsion Laboratory and Ames Research Center in California, Stanford University in the first three months of the year developed a high-fidelity, multidisciplinary computational approach for the simulation of supersonic parachute inflation dynamics and the prediction of the associated drag and structural integrity. ★

Contributors: *Chris Rumsey, Nathan Hariharan, Andrew Wissink, Charbel Farhat, Keith Bergeron, Jennifer Abras*

▼ **Unsteady solution** of a UH-60 in forward flight using fully automated strand gridding/solution methodology. User provides surface grids, and entire volume grid sequence is generated during runtime.

Andrew Wissink/U.S. Army

Landmark launches are signals of future planetary exploration

BY BRIAN C. GUNTER

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

NASA/Caltech

▲ **An artist's rendering** of the twin Mars Cube One spacecraft flying over Mars.

This year was marked by the launch of a number of satellites as well as major milestones for other ongoing missions. In February, SpaceX tested its Falcon Heavy rocket, which is designed to deliver up to 63,800 kilograms to low Earth orbit, the most capacity of a launch vehicle since the Saturn 5 rockets of the Apollo era. The test launch culminated in the autonomous, simultaneous landing of the vehicle's two first-stage boosters in Florida as planned. The center core rocket was not recovered but SpaceX is expected to try again on future launches.

In May, **NASA's InSight lander launched toward Mars** with an expected arrival date in November. Joining the lander on its trajectory to Mars were the first planetary nanosatellites, or cubesats. The **Mars Cube One cubesats**, each with a mass of 13.5 kg, were scheduled to perform a Nov. 26 flyby of Mars to coincide with the descent and landing of InSight, providing communication relays to Earth. The small satellites separated from InSight shortly after reaching their escape trajectory near Earth, meaning the cubesats navigated independently to Mars and will need to be precisely at the right place at the right time for the relay operations.

After a four-year journey, in June the **Hyabusa2 spacecraft arrived in orbit around asteroid Ryugu,** deploying a canister with two rovers to the surface in September and a lander in October. The weak gravity field of the asteroid makes normal wheeled motion difficult, so the rovers "hopped" across the surface. The **Japan Aerospace Exploration Agency, or JAXA,** spacecraft and rovers will spend the next year and a half studying the asteroid, after which the spacecraft will return to Earth with a cache of samples that will add new insights to the origin and evolution of our solar system. On a similar note, NASA's OSIRIS-REx mission also began its approach phase in August to the 500-meter-diameter asteroid Bennu. By December, OSIRIS-REx was to have executed a series of complex maneuvers to come within 7 kilometers of the asteroid's surface. In addition to gathering numerous remote sensing observations of the asteroid, the spacecraft will eventually gather a sample from the surface using a robotic arm and return the sample to Earth.

Following its August launch, NASA's **Parker Solar Probe on Nov. 5 skimmed by the sun at a distance of 24 million kilometers, far closer than any other spacecraft has come. At this perihelion, Parker also set a new record for spacecraft speed of 343,100 kph.** In the coming years, the spacecraft will ultimately reach a closest approach distance of just 6.16 million km (compared with Earth's mean distance to the sun of 150 million km and Mercury's mean distance of 58 million km) at a speed of 692,000 kph and survive temperatures up to 1,377 Celsius. The mission design involves a highly elliptic orbit and seven Venus flybys.

Closer to home, earlier this year, NASA launched two spacecraft that will continue measurements of Earth's time-varying gravity and topography. The Gravity Recovery and Climate Experiment Follow-On, or GRACE FO, mission, launched in May, consists of twin satellites in a near-polar orbit. The redistribution of mass at Earth's surface due to changes in the solid-earth (e.g., earthquakes) and hydrosphere (e.g., aquifers, glaciers, oceans) cause small variations in the gravity field, which in turn cause GRACE FO satellites' orbits to also change slightly. These orbit variations are detected by the satellites' intersatellite ranging systems, which allow the monthly gravity fields to be inferred. The ICESat-2 mission, launched in September, will combine precise orbit determination (centimeter level) and precise attitude determination (arcsecond level, or 1/3,600 of a degree) to geolocate the energy returns of the mission's laser pulses and precisely map the topography of the land and ice sheets over time. GRACE FO and ICESat-2 will provide valuable insight into many of Earth's dynamic processes, both natural and man-made. ★

Forecasting space weather to protect travelers

BY MATTHEW J. PRUIS

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

Space weather affects the daily lives of many people in subtle ways. One example is radiation exposure on aircraft. Flights can be diverted to lower radiation regions so people onboard spend less time in higher radiation areas. A variety of phenomena contributes to space weather, from galactic cosmic rays, to solar flares, to the Van Allen radiation belts, and the corresponding variability requires simulating or observing processes that vary on scales from hours to years.

To help enable air traffic management to monitor global radiation "weather," the Automated Radiation Measurements for Aerospace Safety, or ARMAS, Flight Module 5 launched on a World View stratospheric balloon in Tucson, Arizona, in March. The ARMAS system uses airborne sensors and ground-based servers to enhance space science research and improve aviation safety. While in flight — which achieved an altitude of 115,000 feet — ARMAS data were retrieved in real time via an Iridium satellite and downlinked to the ground for use by NASA's Nowcast of Atmospheric Ionizing Radiation for Aviation Safety, or NAIRAS, model of the global radiation environment. ARMAS data in NAIRAS yields an improved accuracy of radiation dose rates along with airborne flight tracks, allowing commercial air traffic to avoid higher radiation areas.

Future improvements in the ability to directly forecast major upcoming space weather events is also expected as NASA's Parker Solar Probe was launched via United Launch Alliances' Delta 4 rocket from Cape Canaveral Air Force Station, Florida, in August. The mission will "touch the sun," flying directly through the solar corona, facing extreme radiation conditions and providing unprecedented, close-up observations of the sun. A 4.5-inch-thick carbon-composite shield is required to protect the spacecraft and instruments from the extreme environment, which will include temperatures of nearly 1,400 degrees Celsius. The Parker Solar Probe observations will address unsolved science questions, such as how the sun's corona is heated and how solar wind is accelerated.

Also this year, NASA completed two tests focused on engine ice-crystal icing. Ice-crystal icing can lead to power-loss events in aircraft when jet engines ingest a large amount of ice crystals during flight in clouds. In January, an ice-crystal icing test using a full-scale engine was completed at the Glenn Research Center's Propulsion Systems Laboratory. In May and June, a second test investigating the fundamentals of ice-crystal icing using a static airfoil took place. This data will help develop ice-crystal accretion modeling tools that ultimately seek to reduce icing issues for future engine designs.

NASA's Langley Research Center, Glenn Research Center and Armstrong Flight Research Center partnered with the FAA to conduct the High Ice Water Content Radar 2 flight campaign, which ended in August. The campaign's goal was to advance work on newly defined pilot weather radar algorithms to identify regions of high ice water content ahead of aircraft. Flights were carried out in the Atlantic and the Eastern Pacific, and the radar identified regions of HIWC approximately 60 nautical miles ahead of the aircraft. Remote identification of HIWC will enable pilots to avoid areas that can cause engine power-loss events and air data system anomalies. ★

▼ **World View's Stratollite** high-altitude balloon lifted off from the company's launch facility in Tucson, Arizona, in March, reaching a float altitude of 115,000 feet carrying instruments to detect radiation.

NASA

Progress seen on self-learning aircraft, Mars landing tech and Dream Chaser

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.

▲ A Black Brant 9 sounding rocket launches from Wallops Flight Facility in Virginia in March carrying a parachute system like the one that would slow the Mars 2020 rover during its descent to the surface of Mars.

NASA's Learn-to-Fly project, in which engineers are testing the feasibility of self-learning aircraft, conducted several successful flight tests. The Learn-to-Fly project incorporates real-time nonlinear aerodynamic modeling with autonomous control law design. The integrated system has the benefit of producing aerodynamic models based on flight data for control law design based on actual flight dynamics responses rather than simulations. Several test flights were conducted at ranges in Virginia at NASA's Langley Research Center and the U.S. Army's Fort A.P. Hill. The flight tests included several varieties of both powered and unpowered aircraft over a span of months in 2018. In some flights, pilots on the ground flew the aircraft via radio control, while others flew under fully autonomous control, and in both stable and unstable configurations. The flight tests demonstrated the feasibility of the Learn-to-Fly concept.

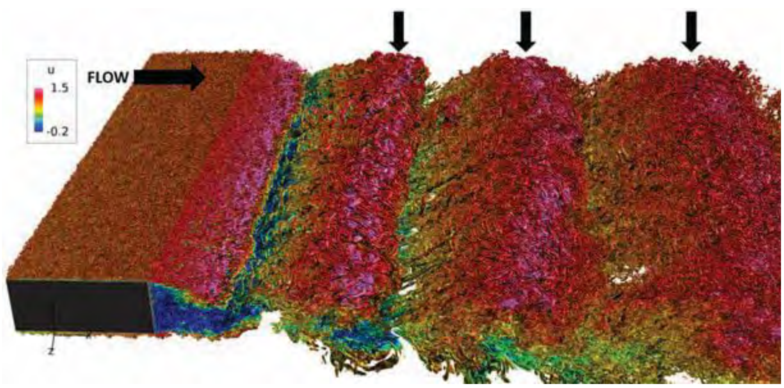
NASA's Advanced Supersonic Parachute Inflation Research Experiment, or ASPIRE, program conducted two flights this year of the parachute system to be used for the Mars 2020 rover landing. In March, a sounding rocket launched from Wallops Flight Facility in Virginia released a strengthened version of the parachute system that delivered the Curiosity rover to the surface of Mars in 2012 in the Mars Science Laboratory mission, targeting the 99 percent expected load conditions. The next flight test occurred in September, targeting twice the observed load of the Mars Science Laboratory mission in 2012. In both cases, the parachute inflated and descended to the surface of the Atlantic Ocean as planned and was recovered, providing a wealth of useful data to NASA engineers. The first ASPIRE flight, conducted in October 2017, tested a build-to-print parachute of the Mars Science Laboratory design, targeting the same load conditions. That flight was also successful.

In February, **NASA issued an "authority to proceed" notification setting a launch window of late 2020 for the first flight of Sierra Nevada Corp.'s Dream Chaser cargo vehicle to the International Space Station**. A few months earlier, in November 2017, a test version of the vehicle completed an autonomous glide and landing test at NASA's Armstrong Flight Research Center located near Edwards Air Force Base, California. The vehicle was lifted to its test altitude of approximately 12,000 feet by a Chinook helicopter and then released. The vehicle executed several planned maneuvers before landing at Edwards. The test validated the final approach and landing phase of the vehicle's guidance and control systems. This successful test was a major milestone in SNC's commercial resupply contract with NASA. ★

Accelerating accurate engineering answers with simulations

BY TIM EYMANN, DAVID GONZALEZ 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.



Ohio State University

▲ **Large-eddy simulations** of compressible shear layers provide insight to aid understanding of physical phenomena such as noise generation and fuel mixing. Flow is from left to right, with turbulent structures colored by streamwise velocity.

This year, fluid dynamics researchers continued maturing high-fidelity large-eddy simulations, or LES, to investigate flow physics. While LES methods have evolved over the past two decades, the accuracy of each simulation remains highly dependent on computational grids, which require significant expertise to create. In June, researchers at the University of Maryland explained how their algorithm-driven method to grid adaptation uses solutions on coarse meshes to drive mesh adaptation. Their method refines the mesh to capture relevant physics and leads to grids with fewer cells for a given accuracy compared with user-generated meshes. Because the number of cells is directly related to the computational expense, the research is showing it's possible to reduce the time to achieve engineering answers with LES, without sacrificing accuracy.

High-fidelity LES simulations performed this year by researchers at Ohio State University with funding from the U.S. Air Force furthered the understanding of emerging propulsion system designs. To gain insight into large-scale flow features that dominate the performance of high-speed engines, researchers at Ohio State focused on three simplified configurations. In March, a group of researchers used LES to explore the unsteadiness associated with shock wave/turbulent boundary layer interactions in a double fin configuration representative of a scramjet internal flow path. In May, another group of researchers at the university examined the flow field downstream of a finite-thickness splitter plate separating two dissimilar streams and used high-fidelity simulations to track periodic, large-scale vortical structures shedding from the geometry. In an actual combustor, this type of shedding degrades the vehicle performance by generating acoustic noise and exciting the structure. The researchers are seeking to understand and mitigate these negative effects. In June, a third group of Ohio State researchers examined a third configuration with LES — the flow around a backward-facing step in a supersonic combustor. Like the splitter plate, a shear layer develops off the step, but here, the resulting flow structures have the positive effect of enhancing the high-speed, turbulent combustion. Their results to date indicate a strong coupling between the reflected shock wave strength and shear-layer reattachment location, a major driver of the physics of the combustor flow field.

Experiments and computational simulations, such as the LES investigations, often generate terabytes of data, making it difficult to extract key physical mechanisms from the studies. Modal analysis is a mathematical technique that facilitates identification of characteristic energy and dynamic modes of a fluid flow. The Modal Analysis of Aerodynamic Flows Discussion Group led by researchers from Florida State University, the University of Minnesota and the Air Force Office of Scientific Research has spent the past few years **reviewing various data-based and operator-based modal decomposition techniques**, culminating in a series of activities in late 2017 and the first half of 2018, including participation in conferences and publication of an overview paper.

An international team of researchers from the Illinois Institute of Technology, U.S. Air Force Academy, Lockheed Martin, BAE Systems, the University of Manchester and the University of Arizona spent this year **investigating the effectiveness of flow control for maneuvering an unmanned combat aerial vehicle**. The jet-powered test vehicle eliminates the need for traditional, deflecting control surfaces by using a flow control system that forces redirected air from the engine through slots in the wings. The four-year project included extensive wind tunnel testing of actuation concepts, computational fluid dynamics simulations of the full aircraft with actuation, and 1:7 scale flight tests of the vehicle in October. ★

Contributors: *Michael Adler, Cory Stack, Johan Larsson, Logan Riley, Jürgen Seidel and Kunihiko Taira*

Facility reactivation and upgrades highlight busy year for 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.

Ground test efforts in 2018 focused on the upgrade and reactivation of several critical test facilities, improvements to facility inspection approaches, and significant gains in test techniques and capabilities.

The National Full-Scale Aerodynamics Complex, part of the U.S. Air Force's Arnold Engineering Development Complex, known as AEDC, returned to operation in June following a one-year recovery effort in the wake of a Class A mishap in June 2017. The mishap destroyed the fan blades on one of six drive motors that power the facility, requiring extensive repairs and a revised drive configuration. Following mishap investigations by NASA and the Air Force, the facility crew undertook an aggressive slate of repairs that included redistributing remaining healthy fan blades to reduce the total number of blades on each drive from 15 to 12. Subsequent checkout runs proved this new drive configuration causes minimal reduction in tunnel performance. The approach has allowed the complex to resume operations in support of customers in the 40-by-80-foot Wind Tunnel. Reactivation efforts continue for the 80-by-120-foot Wind Tunnel, and longer-term efforts are underway to replace and eventually upgrade all the blades in the fan drive.

Elsewhere at AEDC, the asset management team at the Aerodynamic and Propulsion Test Unit continued work on establishing a new inspection technique to detect flaws and cracks in the high-pressure vessels they use to run the von Kármán Gas Dynamics Facility. This effort began late in 2017. Previous inspections required significant downtime and manpower, as 90 pressure bottles had to be physically removed to allow extensive X-rays and other inspections to check for cracks. The new approach, which had been deployed previously at other facilities, involves using existing compressors to stress the bottles in situ to slightly above their normal capacity and installing specialized acoustic sensors to listen for any leaks or crack propagation. AEDC estimates the new approach will provide more than $300,000 in total savings and create much less downtime during the course of the current system recertification effort.

The facility team at NASA's Glenn Research Center continued to work throughout the year on a major upgrade to the acoustic qualities of the 9-by-15-foot Low-Speed Wind Tunnel, or LSWT. The work began in June 2017, and the team expects to complete modifications and testing by the end of 2018, allowing calibration and customer testing to resume in 2019. NASA has operated the LSWT since 1969; it was equipped with an acoustic treatment in 1986. Following that upgrade, the tunnel began focusing primarily on performing aeroacoustic and aerodynamic performance testing for NASA and industry propulsion systems. Aircraft engines have been getting consistently quieter, and some engine model concepts operating at low power generate noise levels that are close to the background noise level of the current acoustic treatment in the LSWT. The planned acoustic upgrades are expected to lower background noise levels by 9.3 decibels (A-weighed), allowing testing at all takeoff and landing flight regime speeds.

Active testing also provided several advancements this year. NASA's Langley Research Center conducted multiple tests throughout 2018 demonstrating new and innovative methods to improve data collection through pressure- and temperature-sensitive paint techniques while expanding the approaches to a broader array of test applications. Meanwhile, the team at AEDC's National Full-Scale Aerodynamics Complex resumed checkout and qualification of NASA's new Tiltrotor Test Rig in its 40-by-80-foot Wind Tunnel in June, following the facility's yearlong reactivation. ★

▼ Workers inspect the new drive fan configuration at the National Full-Scale Aerodynamic Complex in Moffett Field, Calif.

NASA

Contributor: *Dave Stark*

Editor's note: *Pat Goulding II works for National Aerospace Solutions LLC as part of the National Full-Scale Aerodynamics Complex project team.*

Falcon Heavy makes history, Parker probe skims by sun

BY JOHN G. REED, 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 guidance, navigation and control field had another eventful year, covering all aspects of aerospace engineering, including launch vehicles, spacecraft, aviation and missiles.

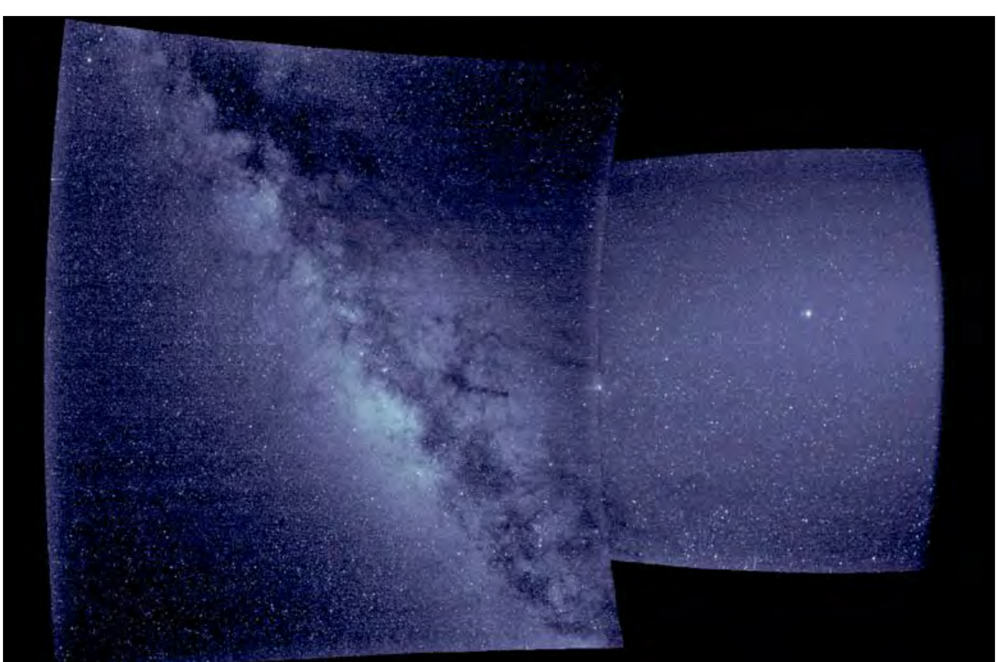
On Feb. 6, SpaceX landed two Falcon Heavy boosters in Florida nearly simultaneously about eight minutes after liftoff from Kennedy Space Center. The core rocket splashed down in the ocean after missing a drone ship where it was supposed to land. This type of rocket innovation is only possible by advancements in guidance, navigation and control, or GNC. Stemming back to the 1980s, the U.S. has invested substantial resources into the development of these so-called "fly-back boosters." This technology manifested from a Department of Defense initiative for a single-stage-to-orbit reusable launch vehicle, with the McDonnell Douglas DC-X, or Delta Clipper, as a prominent example that pushed the limits of GNC technology in the early 1990s. Almost 30 years later, it seems these types of GNC heroics will become commonplace with the earlier concepts and tests woven into the fabric of the aerospace community.

In the early morning of Aug. 12, NASA's Parker Solar Probe launched from Kennedy Space Center, beginning its journey to the sun. The mission's objectives are to trace the flow of energy from the sun, understand the heading of the solar corona and explore what accelerates solar wind. On Aug. 21, **the GNC team nailed the critical first trajectory correction maneuver**. Andy Driesman, Parker Solar Probe project manager who works at Johns Hopkins University Applied Physics Laboratory, said the burn's execution was "exceptional, measuring at less than 0.2 percent magnitude error — which translates to a 0.3 standard deviation."

The Parker Solar Probe team executed two more burns in August setting the probe's trajectory for the mission: For the rest of its journey, the probe will need only minor trajectory-correction maneuvers. The spacecraft performed its first of seven gravity assists with Venus in October, and its first perhelion pass on Nov. 5. It flew as close as 24 million kilometers to the sun, withstanding a temperature of 710 kelvins. The mission controllers received an "A" beacon on Nov. 7, after the pass, indicating a healthy spacecraft. It was not only the closest any spacecraft has gotten to the sun, but also the fastest, at 343,100 kph. The spacecraft will transmit the science data it recorded in its first solar encounter in the middle of November, beginning a revolution in our understanding of the star that makes life on Earth possible.

While the industry works to bring new small satellite launchers to market, on Sept. 12, **United Launch Alliance launched the final Delta 2 rocket** carrying NASA's Ice, Cloud and land Elevation Satellite-2. The Delta 2 first launched Feb. 14, 1989, and had launched 155 times since then. Delta 2 pioneered the use of the L3 Technologies Redundant Inertial Flight Control Assembly guidance and control system in 1995. This fault-tolerant system carried over in the design of the Boeing Delta 4 heavy-lift launchers. Internationally, two Earth observation satellites for Britain's Surrey Satellite Technology Ltd. lifted off Sept. 16 on India's lightest version of the Polar Satellite Launch Vehicle, or PSLV. The launch highlighted the United Kingdom's desire to further commercialize production of the PSLV, a rocket often used for small satellite missions. ★

▼ **The Parker Solar Probe** in September took snapshots of the Milky Way to verify that its camera, called WISPR, short for the Wide Field Imager for Parker Solar Probe, was pointed correctly. The bright spot in the right image is Jupiter.



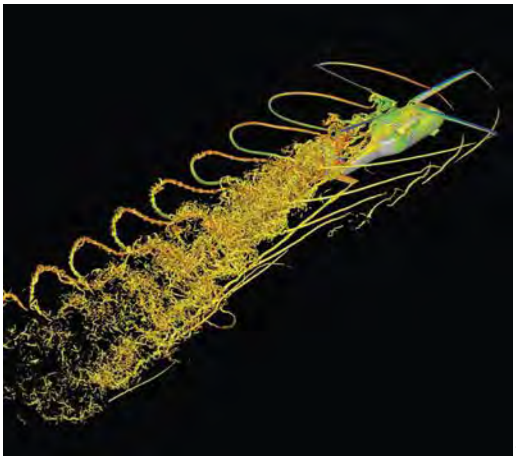
NASA, U.S. Naval Research Laboratory

***Contributor:** Jayant Ramakrishnan*

Meshing, visualization community works on CFD Vision 2030

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.



Andrew Wissink/U.S. Army

▶ This flow solution for a UH-60A in high-speed forward flight was obtained with automatically generated strand/Cartesian grids in Helios.

The meshing, visualization and computational environments community continued work this year on technologies and techniques for NASA's CFD Vision 2030 goals to transform the digital landscape in aerospace analysis.

Computational meshes are necessary to discretize the region of interest when analyzing aerodynamics systems using computational fluid dynamics. To address the requirement that computational meshes be versatile enough to be applied to problems involving transient and dynamic environments where surfaces are not rigid or are in motion relative to each other, the U.S. Air Force in June awarded three Phase 1 Small Business Innovation Research, or SBIR, contracts to provide geometry kernel support to enable dynamic simulations involving surface mesh deformation, adaptive mesh refinement and nonlinear surface elements. The Phase 1 awards went to CFD Research Corp., Pointwise Inc. and GoHypersonic Inc. In addition to the Phase 1 Air Force SBIR, Pointwise also received a NASA Phase II SBIR in April focusing on high-order, curved meshing and adaptation.

An important part of generating computational aerodynamic solutions is the ability to capture the required level of fidelity in the necessary regions. A recognized technique for achieving this is grid adaptation. In January, **Boeing demonstrated results using its EPIC anisotropic mesh adaptation code**. The adaptive mesh generation process executed automatically without intervention, saving many weeks of effort relative to a fixed mesh approach. It also enabled optimal placement of nodes and better alignment of mesh elements with geometric and flow field features, which in turn resulted in better mesh resolution with fewer elements.

Based on Moore's law, the largest CFD problems are expected to be using 1 trillion cells by 2030. Conversely, the disk-read data transfer rate is only doubling every 36 months and is destined to be a bottleneck for traditional post-processing architectures. To eliminate this bottleneck, **Tecplot Inc. is developing a subzone load-on-demand visualization architecture that loads only the data needed to create the desired visualization**. The company released the latest version of this technology in March and in June used it to visualize an iso-surface for a simulated 1 trillion cell dataset on an engineering workstation with 128 gigabytes of memory, which was nearly two orders of magnitude less than the 8.5 terabyte file size.

As higher order computational analysis becomes more mature, the demand for the capability to view high order solutions increases. Even if high order solutions are available, they are of limited value if the ability to post-process the solutions does not keep up with the ability to generate them. However, in March, **Kitware released a new high order visualization capability for ParaView, its open source data analysis and visualization application**. The company added support for ParaView for arbitrary-order Lagrange elements and advanced the state-of-the-art in visualizing high order images and post-processing high order data.

On the computational environments front, the Air Vehicles branch of the U.S. Department of Defense Computation Research and Engineering Acquisition Tools and Environments program released new versions for both its fixed-wing (Kestrel) and rotary-wing (Helios) frameworks early in the year. Kestrel continues to add capabilities to address targeted applications for the research, development, test and evaluation community and in September introduced a motion preview capability in the user interface that allows the user to animate a prescribed motion or play back the motion of a past case. A major advance for Helios was its addition of automated strand meshing. Using this capability, which was released in January as part of the new production version, a user supplies a surface mesh and Helios can then automatically construct the entire volume mesh in parallel at runtime. ★

Editor's note: *Carolyn Woeber works for Pointwise.*

Simulating air traffic control for training pilots

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.

Today, even in the most sophisticated flight simulators used for pilot training, the role of air traffic control, ATC, is played by the instructor. Flight crew experiences can vary due to differing instructor skills and focus. Additionally, other moving aircraft are rarely simulated. With vacant taxiways, runways and airways, the synthetic environment is sterile and quiet when compared with increasingly busy traffic levels in the real world. Combined, these limitations result in lighter crew workloads in the simulator than in actual operations.

Advances in artificial intelligence, speech recognition and synthesis are prompting a resurgence in simulating the ATC environment for training scenarios. This technology promises to increase immersion, to offer more realistic workloads by fully automating the ATC function and introducing realistic traffic, and to free up the instructor to focus more on core observation and training tasks. Simulating the ATC environment has progressed to the stage that international guidance and requirements are being revised for its use. Trials look promising and several major airlines have expressed interest, even though it is not yet mandated by regulation.

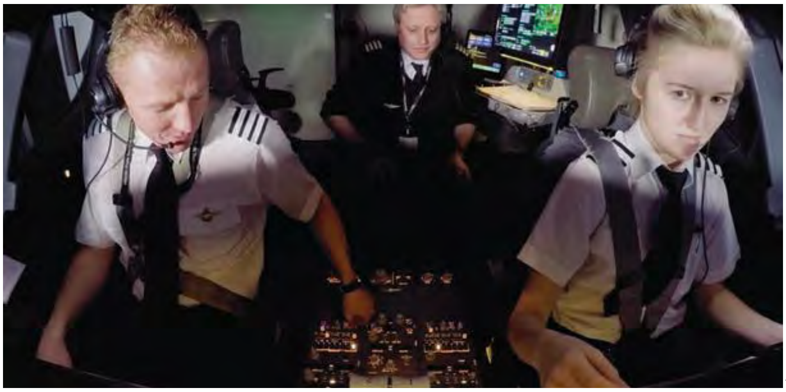
As a follow-up to experiments performed in 2017, **two level-D training simulators at the FAA Aeronautical Center in Oklahoma City were used this year to verify possible simplified go-around criteria for commercial transport aircraft under different environmental conditions**. While most airlines have stabilized-approach criteria as part of their standard operating procedures, a 2012 Flight Safety Foundation study showed crews conduct a go-around only 3 percent of the time when outside of these criteria. The simplified criteria developed in these experiments hopefully are more in line with current airline operations and would ultimately contribute to improving the current go-around compliance rate.

A study to help define parameters for simulator benchmarking was completed in June on the vertical motion simulator, VMS, at NASA's Ames Research Center in California and in August on the Simona Research Simulator at Delft University of Technology in the Netherlands. The same experiment was conducted in both simulators, investigating the effect of different motion-filter orders on pilot control behavior and performance. Results of this comparison between the VMS and Simona will help to provide insights into benchmarking standards important for replicating human performance results in flight simulators.

The FAA has mandated pilots be trained in full stall and upset recovery starting in 2019. Because this training involves more maneuvering than typical airline training tasks, additional burdens are placed on a simulator in order to provide adequate motion cues. Optimization of those cues may lead to improvements in transferring skills learned in a simulator to actual flight. **Experiments were conducted this year at the NASA Ames Research Center's VMS to investigate motion cueing for stall recovery training.** The VMS was chosen because it can simulate small hexapod motion and much larger motion closer to real flight. The experiment findings will be used to publish motion cueing guidelines for effective stall recognition and recovery training.

In preparation for future integration of unmanned aircraft systems into the naval fleet and on aircraft carriers, Systems Technology Inc. this year developed the on-Deck Intelligent Aircraft Body Language Observer system, or DIABLO, which combines inertial measurement unit-embedded signalman wands and machine learning to facilitate gesture recognition and communication between on-deck aircraft directors and unmanned aircraft taxiing about the carrier deck. This system was evaluated in Manned Flight Simulator's Lab 8 dome simulator at Patuxent River Naval Air Station, Maryland, in which an aircraft director with DIABLO signalman wands interacted in a simulated aircraft carrier deck environment and with an unmanned aircraft taxiing along the deck. The results and feedback from the directors show promise that this system could be the solution to communication between deck personnel and an unmanned plane. ★

▼ **Advances in artificial** intelligence, speech recognition and synthesis help simulate the air traffic control component for training scenarios. In this flight simulator manufactured by Multi Pilot Simulations, the instructor, center, can focus on training rather than playing the air traffic control role.



Quadrant Group

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

Plasma diagnostics in forefront of research

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.

Notable advancements were made in the area of plasma diagnostics this year. Researchers at Princeton University have been pioneering the development of electric-field-induced second harmonic generation, or E-FISH, for spatially and temporally resolved measurements of rapidly time-varying electric fields. The researchers achieved one-dimensional, spatially resolved measurements of nanosecond-pulse-generated ionization waves with a temporal resolution of 100 picoseconds and spatial resolution lower than 50 microns. Between the end of last year and June, researchers at Ohio State University applied E-FISH to measure electric fields in dielectric barrier discharge plasma flow actuators powered by alternating current and nanosecond pulse waveforms, as well as in atmospheric pressure flames enhanced by nanosecond pulse and alternating current discharges. Purdue University and Princeton University researchers in February reported the first direct measurement of absolute plasma electron numbers generated in multiphoton ionization, or MPI, of air using a microwave scattering technique; this offers decreased uncertainty in determining MPI cross-sections and photoionization rates.

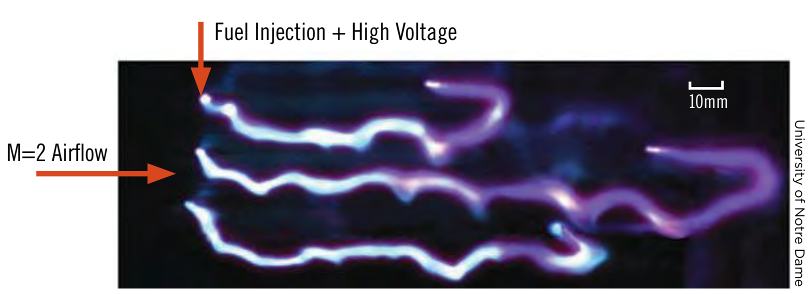
In the area of plasma-assisted ignition and combustion, scientists from the University of Notre Dame published work in May on long filamentary plasmas called Plasma-Injection Modules to realize fuel ignition and improve combustion efficiency under supersonic conditions. An important feature of this approach is the self-localization of the plasma in the shear layer between the fuel and oxidizer, enhancing mixing and promoting chemical reactions. In August, researchers at Xi'an Jiaotong University reported on **a multichannel plasma ignition method that can extend the ignition range for combustors operating under low-temperature, low-pressure and high-speed conditions.**

Representing a significant advancement for plasma-assisted combustion, or PAC, modeling capabilities, Princeton's PAC chemical mechanism was submitted for publication in July, completed with direct measurements of quenching rate coefficients of electronically excited nitrogen and nitrogen ion states by different hydrocarbons. Princeton researchers built and tested the kinetic model of heat release dynamics in nanosecond-pulsed plasma afterglow, including ozone production dynamics.

Novel plasma flow control devices were also demonstrated this year. In April, Iowa State researchers reported on **alternating current and nanosecond pulsed dielectric barrier discharges, or NS-DBDs, as anti-icing and de-icing mechanisms on airfoils.** NS-DBDs exhibited superior performance compared with conventional heater methods using the same power input. Princeton University researchers also applied NS-DBDs to improve static and dynamic stall characteristics in rotorcraft and, in August, reported up to 40 percent increased lift force in 20 to 70 meters per second flows for angle-of-attack up to 32 degrees. In June, University of Illinois and CU Aerospace researchers reported further development of cyclotronic arc-plasma actuators, or CAPAs, devices that produce Lorentz forcing on an arc-filament formed between coaxial electrodes within a strong magnetic field, to induce vortices in boundary layer flows. The compact devices produced more than 6,000-revolutions-per-minute rotation rates with 5-10 m/s plasma filament speeds; the Illinois-CUA team plans to demonstrate CAPAs as low-drag on-demand vortex generators on drones in 2019.

In May, Princeton University researchers reported **the first demonstration of the backward lasing from atomic argon in atmospheric pressure air.** In the process, air containing 0.8 percent argon was optically pumped via three-photon resonant excitation at 262 nanometers, producing a backward-propagating 1,409 nm emission returning along the pump beam path. Lasing occurred within tens of picoseconds following the pump and was obtained at distances ranging from 20 centimeters to 2 meters. A 100 femtosecond laser provided high intensity to drive the process, with efficient pumping due to the overlapping broadband spectral components of the pumping pulse compensating each other to achieve narrow-linewidth excitation of the upper level. ★

***Editor's note:** Sally Bane works at Purdue University, and Joseph W. Zimmerman works at CU Aerospace.*

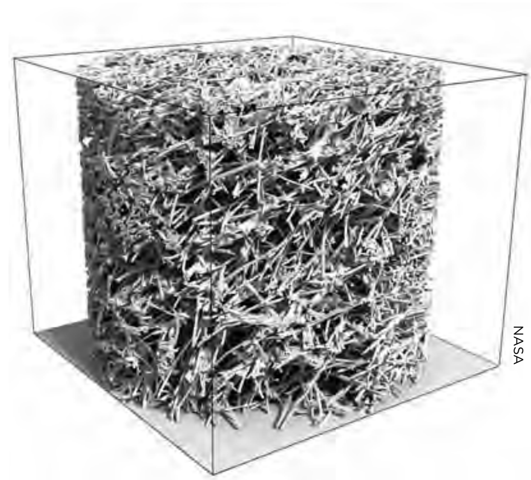


▼ **Three plasma injection** modules operating in Mach 2 airflow in a supersonic test facility at the University of Notre Dame. The electrical discharge originates from the fuel injection nozzle and follows the fuel jet downstream, producing enhanced mixing in the shear layer and increasing the plasma-fuel interaction time.

New technologies advancing thermophysics

BY AARON BRANDIS, JONATHAN BURT AND BRENTON TAFT

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



Microtomography of FiberForm, the substrate of NASA's Phenolic Impregnated Carbon Ablator. The displayed volume is a rendering of a 1.66-millimeter edge cube.

A test campaign beginning in October in the new Laser Enhanced Arc-jet Facility, or LEAF-Lite, at NASA's Ames Research Center in California allows for test articles to be heated by both convective and radiative heat flux simultaneously, making the facility more representative of actual flight conditions. LEAF-Lite uses multiple 50-kilowatt continuous wave lasers to add the ability to simulate radiative heating on thermal protection materials. Radiative heating is more prevalent in missions with higher atmospheric entry speeds like the Orion spacecraft or interplanetary scientific probes. Using this new system, researchers can simulate radiant heating with the laser and convective heating with the arc-jet simultaneously on a single test article. During its initial test in October 2017, the lasers radiatively heated a 6-inch-by-6-inch Avcoat wedge sample up to 405 watts per centimeter squared while the arc-jet simultaneously provided 160 W/cm^2 of convective heat, resulting in a total heat flux of 565 W/cm^2. The test campaign in October 2018 was to expand the laser spot size to 17 inches by 17 inches to test an Orion Thermal Protection Systems panel.

This year, **for the first time, microtomography was used to resolve microstructures of heatshield materials NASA spacecraft use during atmospheric entry**. These experiments, performed throughout the year at the Advanced Light Source at Lawrence Berkeley National Laboratory in California, provide a tool to nondestructively image 3D structures at scales from hundreds of nanometers to centimeters. The fibrous architecture is resolved in 3D with an unprecedented level of detail, enabling interactive inspection of the material at high resolution and statistical characterization of its structure's variability. Analysis of microtomography data allows for material properties to be calculated and to simulate material response at the micron scale. Having material data at the micron scale has led to active research efforts, both at NASA and in academia, aimed at developing large-scale computational methods based on digital microstructures.

In March, **a preliminary design review was conducted for the high lift motor systems on NASA's X-57 Maxwell experimental aircraft**. The X-57 is intended as a testbed for distributed electric propulsion technologies. The thrust from two wingtip-mounted propellers is augmented during takeoff and landing by 12 high-lift electric motors and propellers that are distributed across the wings. These technologies provide beneficial propulsion-airframe interaction, with substantially increased cruise efficiency through characteristics including a reduction in wing planform area. In a novel thermal management approach for the high lift motors and associated motor controllers, heat pipes are part of a passive cooling system that allows convective removal of electrically generated heat through the skin of wing-mounted nacelles. Flight tests, scheduled to begin in 2019, will make use of a new mission planning tool that incorporates electrical component thermal loads in trajectory optimization calculations, with the goal of maximizing range while meeting the unique thermal management requirements of an all-electric propulsion system.

In September, **the U.S. Air Force Research Laboratory's second Advanced Structurally Embedded Thermal Spreader, or ASETS-2, flight experiment passed one year of on-orbit operations aboard Orbital Test Vehicle 5**. ASETS-2 is made of three low-mass, low-cost oscillating heat pipes and an electronics/experiment control box. The three oscillating heat pipes are of varying configuration (center heating with single- and double-sided cooling) and working fluids to isolate specific performance parameters of interest. As of November, the ASETS-2 flight experiment had exhibited no degradation and had achieved two primary science objectives by measuring the initial on-orbit thermal performance and long-duration thermal performance. Having conducted multiple six-week tests this year, ASETS-2 set a record for the longest continuous on-orbit operation. Returned flight experiment hardware will be subjected to post-flight testing to assess the presence of any noncondensable gas that may have formed on orbit. ★

Contributors: *Francesco Panerai and Geoffrey Cushman*

Space, military delivery systems undergo testing

BY RICHARD BENNEY, IAN CLARK, RICARDO MACHIN

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.


NASA

A strengthened version of the 21.5-meter Disk-Gap-Band parachute that landed the Curiosity rover on Mars in 2012 was flown on a test flight in March 2018.

In the space realm, NASA's Jet Propulsion Laboratory in California conducted the second and third flights of the supersonic parachute system for the Mars 2020 rover mission. A two-stage sounding rocket was launched from Wallops Flight Facility in Virginia and released this parachute over the Atlantic Ocean at an altitude and Mach number to produce conditions relevant to those of a Mars entry. The parachute inflated and in the last test withstood a 300 kilonewton inflation force.

These Advanced Supersonic Parachute Inflation Research Experiments, ASPIRE, mark **the first full-scale supersonic parachute tests in direct support of a Mars mission since the Viking missions to Mars of the 1970s**. The March and September flights were different from ASPIRE's debut flight in November 2017 in that engineers flew a strengthened version of the 21.5-meter-diameter Disk-Gap-Band parachute design. Incorporating stronger suspension lines and a new specification of woven Nylon broadcloth, the strengthened design was tested at dynamic pressures above 1,000 Pascals and Mach numbers near 2.0. The inflation loads for both tests were the highest supersonic loads ever survived by a parachute of this scale.

Also, the **NASA Orion Capsule Parachute Assembly System completed qualification testing** in September with the final of eight airdrop tests performed at the U.S. Army Yuma Proving Grounds in Arizona. The final model and simulation validation as well as requirement verification were scheduled to continue with the System Acceptance Review expected in late 2019. This acceptance will mark the certification of the parachute system for human missions. The expertise accumulated during this project has been applied to NASA's interaction with Commercial Crew Program Aerodynamic Decelerator Systems design and qualification testing.

Turning to defense, **the U.S. Army Natick Soldier Research, Development, and Engineering Center conducted hundreds of airdrop tests averaging nine lifts and 50 payloads per week every two months** this year to include the next generation high altitude self-guided airdrop systems in the 20- to 200-kilogram weight range with technology for vision navigation in a GPS denied/degraded environment and increased accuracy/maneuverability for urban navigation. This was done under a program called AAIRDUCT, short for the Autonomous Aerial Insertion and Resupply into Dense, Urban, Complex Terrain. The program was started in March after the Office of the Secretary of Defense approved AAIRDUCT as a fiscal 2018 new start Joint Capability Technology Demonstration with numerous partner organizations. Another is **dispersion of information material, such as leaflets or humanitarian aid, directly to populated areas safely with the Multi-Use Aerial Dispersing System**. This system is released from a high altitude and deploys its small payloads from a larger airdrop bundle at a specific altitude and location to optimize dispersion to a targeted area.

The Natick center, which invests in new component development, began modeling and simulation efforts to design for the lowest release altitude possible of the Heavy Equipment Large Low Velocity Airdrop System, a project that began in May. It seeks to expand airdrop capability from the fielded Low Velocity Airdrop System maximum all up weight of approximately 19,000 kilograms to a weight of about 36,000 kilograms, utilizing the C-17 aircraft. Areas of investigation this year included the aircraft extraction system, cargo platform and performance of existing Army parachutes in larger clusters, and include prototype components and ground/structural testing.

The Natick center also investigated flow-induced vibrations, motivated by vibrations experienced by parachute suspension lines, in work that will continue in 2019 under the leadership of Army researcher Keith Bergeron. Using cyber-physical fluid dynamics experiments and fluid-structure simulations at the University of Massachusetts Lowell, researchers will continue their integrated approach to include modeling of torsional stiffness properties for braided cords and a new series of computational fluid dynamics simulations. The 2018 research was done in collaboration with the aerodynamics team from the Institut Supérieur de l'Aéronautique et de l'Espace, in Toulouse France, which will continue participating in 2019. The objective is to develop a better understanding of the drag contribution made by suspension lines and new designs to optimize parachute performance. ★

NASA

Building a structure for 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.

▲ **NASA's Ikhana** Predator B unmanned aircraft, in a test flight, flew without a manned safety chase aircraft in high-altitude public airspace.

According to the International Air Transport Association, global airline industry profits are projected to dip from $38 billion in 2017 to $33.8 billion in 2018 because of a projected 25.9 percent increase in fuel prices and a 2.2 percent increase in labor rates this year. However, this still represents a robust return on invested capital of 8.5 percent. In North America, a net post-tax profit of $15 billion is expected in 2018, with a net post-tax profit margin of almost 6 percent. This strong economic performance is attributed to the consolidation of commercial airlines, which has helped maintain high passenger and cargo loads.

Beyond traditional aviation, **urban air mobility, or UAM, became a significant area of interest in industry, academia and government** this year. In September, NASA announced plans to host a series of UAM Grand Challenges in which the UAM community demonstrates designs that address foundational UAM safety and integration barriers, with the first event expected in late 2020.

UAM includes aircraft with pilots onboard and UAS, short for unmanned aircraft systems, conducting scheduled and/or on-demand operations between dedicated and/or ad hoc takeoff and landing areas along fixed or temporary routes in metropolitan areas that could include airspace that conventional aircraft use. Among UAM under development are hybrid electric or fully electric vehicles that could conduct a wide range of missions, including transporting people and goods and assessing ground traffic. UAM stakeholders are working together to build the required structure that includes vehicle manufacturing, battery development, vertiport design and construction, and air traffic management. The UAM community will need to work together with the broader aviation community to demonstrate that UAM aircraft can be operated safely with other aircraft and people and property on the ground.

NASA made a significant advancement toward routine operations of unmanned aircraft in the National Airspace System when it **flew an Ikhana Predator B aircraft without a manned safety chase aircraft in high-altitude airspace used by commercial and private aircraft**. NASA worked closely with the FAA to conduct this historic flight. The Ikhana aircraft flew in accordance with FAA standards for large UAS using equipment developed by industry partners General Atomics and Honeywell.

In addition to large UAS, a significant step has been taken toward the routine operation of small UAS. **The national beta test of the Low Altitude Authorization and Notification Capability, or LAANC**, was rolled out in six waves between April and September at nearly 300 air traffic facilities covering approximately 500 airports. LAANC is the first initiative of the FAA UAS Data Exchange Program for facilitating the sharing of airspace data between the government and small UAS operators. LAANC automates the application and approval process for the FAA to authorize small UAS operators to fly under 400 feet in controlled airspace around airports. Requests submitted by operators are checked against airspace data (e.g., temporary flight restrictions) in the FAA UAS Data Exchange. Compared with manual authorizations that could take weeks, LAANC enables small UAS operators to receive authorization in near-real time. ★

The AIAA Foundation made an impact on the Diversity Scholars pictured above by helping them attend AIAA SciTech Forum so they could learn about their future workforce!

New designs offer promise of speed and utility

BY MICHAEL J. LOGAN AND MICHAEL L. DRAKE

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

Existing aircraft manufacturers brought out new models, and new companies developed concepts for urban air mobility and other applications this year. Numerous first flights were conducted, making this an exciting time for aircraft designers.

Existing aircraft companies such as Gulfstream, Boeing and Airbus continue to innovate with new configurations and modifications of existing ones. **The Gulfstream G500 earned its type certificate and production certificate** from the FAA in July. The G500 can fly 9,630 kilometers at its best cruise speed; at its high-speed cruise of Mach 0.90, the G500 will fly 8,149 kilometers. The aircraft has earned more than 20 city-pair speed records, most of them at Mach 0.90. In March, Boeing had its first flight of the 737 Max 7, the smallest variant of the new 737 Max line. According to Boeing, "The Max 7 has a range of 3,850 nautical miles, the longest of any Max family airplane." Both **the Boeing 787-10 and the Boeing 737 Max 9 in Feburary received their FAA certification to begin deliveries**. Major developments on Boeing's military aircraft side included the selection in August of its MQ-25 Stingray design as the U.S. Navy's new carrier tanker drone. A month later, the U.S. Air Force chose Boeing's new design for the T-X trainer, replacing the Northrop T-38 Talon.

In July, European manufacturer Airbus flew its new BelugaXL aircraft designed to provide large aircraft component transport. The BelugaXL is based on an A330-200 freighter aircraft and is powered by two Rolls-Royce Trent 700 engines. Airbus said that "the lowered cockpit, the cargo bay structure and the rear-end and tail were newly developed jointly with suppliers, giving the aircraft its distinctive look." **The Airbus Perlan 2 glider set a world altitude record**, exceeding 76,000 feet in early September. This subsonic flight even exceeded the maximum powered subsonic aircraft record set by the U-2. Airbus also delivered the first A321neo Cabin Flex to Turkish Airlines in July. The aircraft has seating for up to 240 passengers and will be the basis of the new A321LR. In February, Airbus delivered the first A350-1000 to Qatar Airways.

General aviation continues to be robust in new vehicle concepts. In August, **Privateer Industries of Titusville, Florida, conducted the first flight of its prototype seaplane, the Privateer**. Equator Aircraft Norway flew its P2 Xcursion seaplane prototype in July. Bye Aerospace flew its solar-electric survey aircraft, or SOLESA, in August. The company hopes to market the SOLESA as a long-endurance aircraft for a variety of missions. Bye also flew the Sun Flyer 2 electric-powered flight training aircraft designed to meet Part 23 requirements.

Airbus' subsidiary A^3 first flew an unmanned version of its urban air taxi, the Vahana, in February. Several companies besides Airbus are vying for a part of the emerging urban air mobility, or UAM, market. The advent of advanced electric power propulsions systems scalable to small manned aircraft has ushered in a plethora of designs from a variety of new companies. The Workhorse Surefly prototype, Pipistrel's Alpha Electro, Magnus eFusion, Kitty Hawk's Flyer, Opener's latest BlackFly, eHang 184 and others had first flights in the past year. Pushing the UAM trend with ideas and funding are companies like Uber, Alphabet and others. Dozens of companies are working to take flight with prototypes within the next year. ★

***Contributor:** Suzanne Swain, Gulfstream*
***Editor's note:** Michael Drake works with Boeing.*

Airbus

▼ **Airbus in July flew** its BelugaXL for the first time. The design is based on an A330-200 freighter.

Aviation operations focus on safety, efficiency and accommodating new entrants

BY TOM REYNOLDS, GABRIELE ENEA, JOHN KOELLING, JEFF HOMOLA AND SAVITA VERMA

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.

Multiple publications in January reported that 2017 was the safest year on record for global commercial aviation, which flew 4 billion passengers on 38 million flights without a fatality on a scheduled jet airliner. This year, as of mid-October, there were 362 airliner fatalities globally, according to the Aviation Safety Network, including **the first fatality on a U.S. airline in over nine years in April when an in-flight engine failure caused cabin depressurization**. Other industry focus areas were improving efficiency during inclement weather, planning for new entrants (e.g., unmanned aircraft systems, or UAS; commercial space; and urban air mobility) and cybersecurity.

Weather is one of the main causes of inefficiency in the aviation system. This year, the FAA emphasized the Plan, Execute, Review, Train, Improve initiative to help support air traffic management decision-making. A particular FAA and industry focus was northeast corridor operations due to their importance to overall U.S. air traffic control system efficiency. An RTCA northeast corridor working group is developing recommendations to improve efficiency of airports throughout the northeast.

UAS integration activities continued this year. **NASA's UAS Traffic Management, or UTM, program conducted flight tests at six FAA drone test sites from March through May**. A variety of technologies representing UTM research areas were tested, including enabling technologies for detect and avoid, communication and navigation, and data exchange between service providers to safely fly in an environment near moderate population levels.

In terms of commercial space, this year saw increasingly regular launches of SpaceX Falcon 9 vehicles, as well as the inaugural launch of the Falcon Heavy in February. Meanwhile, Blue Origin, Virgin Galactic and other commercial space companies edged closer to regular operations. The FAA is developing decision support systems to help facilitate safe, efficient and equitable access to airspace as space and other new entrants evolve.

Urban air mobility, or UAM, is another emerging focus area. NASA, Uber and others introduced or explored a range of air vehicle designs and concepts of operation suitable for transporting a small number of passengers at short ranges (up to four people up to 100 nautical miles) in urban environments. Candidate vehicles include conventional rotorcraft and electric vertical takeoff and landing configurations. Some of the main challenges are the impact of aircraft noise in urban environments and safe integration with other airspace users. NASA's System-Wide Safety Project is tasked with ensuring the safety of these new vehicles and operations. Specific focus areas include developing technologies to monitor, assess and mitigate anomalies in the airspace, developing tools and methodologies to help certify increasingly autonomous systems, and improving the human ability to monitor them.

The FAA ramped up efforts to study the potential cyber risks to the aviation ecosystem, funding multiple research projects. The risk is not limited to the aircraft; in fact, there were multiple reports of cyberattacks on airports around the world. In March, Atlanta's Hartsfield-Jackson International Airport's Wi-Fi was disconnected because of a ransomware attack to the city administration. In September, another ransomware cyberattack made flight displays go blank for two days at Bristol Airport in the United Kingdom. ★

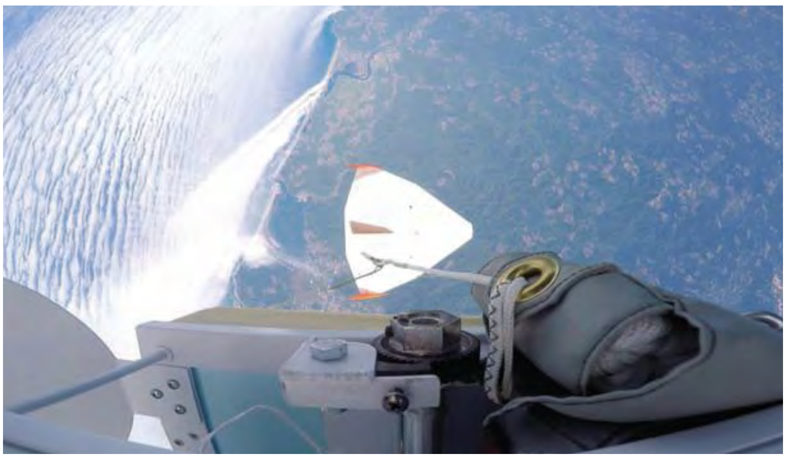
▼ **A drone flies during** a NASA test of its UAS Traffic Management system.

NASA

Balloons support space flight, internet communications, scientific research

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.



Near Space Corp.

▲ **Autonomous High Altitude Shuttle System**, or HASS, glider being released from a balloon 94,000 feet above the Oregon coast.

Balloon systems experienced significant advances and set records this year. Oregon-based Near Space Corp. continued development of its High Altitude Shuttle System, or HASS, a balloon-launched glider designed to support airborne research and enhanced payload recovery. Work this year aimed to create a research-grade microgravity platform by flying repeated parabolic profiles during HASS' gliding descent at near-transonic speeds in the stratosphere. In August, the company attempted a microgravity flight by dropping the HASS from 94,000 feet over the Oregon coast. Although the glider went transonic and suffered a control loss during this attempt, it descended safely into the coast range. Numerous previous HASS flights have been released from as high as 92,000 feet, landing autonomously back at the launch site, Near Space Corp.'s Tillamook UAS Test Range. More flights are expected in early 2019.

In June, **Loon, a company developing stratospheric balloons for internet communications, became an independent business within Alphabet**, the parent company of Google. The next month, Loon announced its first commercial deal, providing balloon-based internet service to parts of Kenya starting in 2019. In August, the company flew seven of its balloons at 60,000 feet in the stratosphere, testing its network technology across 1,000 kilometers of the western United States.

In August, France's National Centre for Space Studies, or CNES, **conducted a scientific zero-pressure balloon campaign with five launches from the Timmins stratospheric base** in Ontario, Canada. One of the balloons carried a pointing gondola dedicated to scientific payloads from the Canadian Space Agency. For the past three years, CNES has been preparing for a validation campaign for its 13-meter-diameter long-duration superpressure balloons designed to circumnavigate the equatorial belt. At the beginning of 2019, six balloons will launch from the Republic of Seychelles with the goal of flying for more than three months and circumnavigating the equator two to three times. This work is in support of the Stratéole-2 project, a study of coupling processes between the upper troposphere and the lower stratosphere in the deep tropics.

The Swedish Space Corp., or SSC, **launched the Italian Space Agency's Olimpo scientific mission** in July from Longyearbyen in Svalbard, Norway. The project aims to map the Sunyaev-Zel'dovich effect that occurs in galaxy clusters. The balloon reached a float altitude of 124,000 feet as it flew west over the Arctic Ocean, Greenland and Canada. New Mexico State University's Physical Science Laboratory provided mission support equipment. SSC commanded the balloon to land on Ellesmere Island, Canada, on July 19, after the balloon had been in the air for six days.

NASA's Scientific Balloon Program flew three balloons carrying large scientific payloads (AESOP-Lite, PMC Turbo and HiWind) from the Swedish Space Corp.'s Esrange Facility in Kiruna, Sweden, to northern Canada over 5½ days in June. NASA also launched two payloads from Palestine, Texas, that month and in August launched two 60 million-cubic-foot balloons from Fort Sumner, New Mexico. These "Big 60" stratospheric test flights carried a suspended load of 680 kilograms and set a sustainable-altitude record of 159,000 feet during the eight-hour flights. This design has only flown once before (in 2002) and is NASA's largest zero-pressure balloon; its low-temperature film underwent extensive testing early this year at Wallops Flight Facility Balloon Research and Development Lab in Virginia. The Big 60 carried several experiments, including two student payloads in NASA's Undergraduate Student Instrument Project and a larger, University of Arizona interplanetary cubesat-antenna experiment. These balloons promise new scientific opportunities by carrying heavy payloads at extremely high altitudes that are inaccessible by other means. ★

Contributors: *Henry Cathey, Scott Coriell, Russ Dewey and André Vargas*

Commercial space enterprises, airspace integrators make test progress

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** continued taxi tests at California's Mojave Air and Space Port.

In commercial spaceflight testing, Stratolaunch, the rocket-launching mothership with the largest wingspan in history, continued taxi tests this year. The California-based company hopes to provide airport-style access to low Earth orbit, as envisioned by Paul Allen, Stratolaunch founder and Microsoft co-founder who died in October.

As part of its efforts to enter the commercial space tourism market, **Virgin Galactic resumed test flights in April of its SpaceShipTwo**, the VSS Unity. The WhiteKnightTwo carrier aircraft released the Unity over Mojave, California. Unity's two pilots flew the prototype tourism craft to Mach 1.87 and an altitude of 84,000 feet, the company said.

SpaceX in February launched a Falcon Heavy rocket for the first time. During the demonstration, two of the vehicle's boosters flew back to and landed on designated landing zones in Florida as planned, but the third booster was lost at sea after the vehicle released a Tesla Roadster as a demonstration payload. The Falcon Heavy has the highest payload capacity of any operational rocket.

In July, Blue Origin took another step toward flying tourists to space when its **New Shepard spacecraft exceeded an altitude of 118 kilometers in an uncrewed test — higher than any previous commercial suborbital space flight test**.

U.S. government and industry partners made progress toward integrating drones into the National Airspace System, with tests of the FAA-developed Low Altitude Authorization and Notification Capability. LAANC is a computer application that provides air traffic separation services at low altitudes. Flight testing was implemented in six waves involving approximately 300 air traffic facilities and 500 airports from April through September. LAANC processes airspace notifications in near real time and automatically approves appropriate requests to access the airspace.

In May, the U.S. Department of Transportation's Unmanned Aircraft Systems Integration Pilot Program, or UAS IPP, selected 10 diverse cooperative flight testing proposals. The aim of the UAS IPP is to further integrate unmanned aircraft into the airspace and reduce risks to public safety and security. The selectees started a three-year test effort focusing on nighttime and beyond visual line of sight operations, flights over people, detect-and-avoid technologies and data link security.

This year, **multiple entities announced flight testing of urban air mobility or "flying taxi" test vehicles with various levels of automation**. In February, the EHang company of Guangzhou, China, released footage of its Model 184 pilotless aircraft showing a flight test with a person aboard. In March, Kitty Hawk Corp. of California revealed an experimental flight test program for its Cora unpiloted air taxi in New Zealand, which was to continue throughout 2018.

Community noise impacts from potential urban air mobility operations are of concern for these emerging stakeholders as well as traditional stakeholders. NASA concluded a multiyear series of flight tests in May to assess acoustic performance of conformal flaps, main landing gear and gear cavity noise reduction treatments. Two NASA Gulfstream G-III test aircraft completed approximately 1,100 passes over microphone arrays. These flight test data will help refine advanced noise prediction methodologies to foster further acoustic improvements in the commercial transport fleet.

In the military realm, the Boeing-built KC-46A tanker aircraft completed developmental flight testing, culminating in an FAA Supplemental Type Certificate issued in September. The test program was to transition to proving full operability of the air refueling systems and preparation for initial operational test and evaluation. The multiyear flight test campaign included approximately 1,600 refueling contacts and 2,200 flight hours. The tanker, based on a Boeing 767 airframe, involves several modifications from the civil airframe.

For passenger flight, Boeing completed its 787-10 and 737-9 MAX flight testing programs, achieving a certification in January for the 787-10 and in February for the MAX. ★

Contributors: *Brent Cobleigh, Paul Bolds-Morehead, James Sergeant and Ken Davidian*

A new X-plane designation, testing highlight year

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.

BY TRAVIS ODOM AND GREG JOHNSTON

About a dozen companies worldwide have committed to flying hypersonic aircraft or space planes commercially, with target dates ranging from 2022 to 2030. Research took place this year that could help the companies as they work toward flight tests.

In June, the Air Force Research Laboratory, or AFRL, and Generation Orbit Launch Services Inc. of Georgia completed an integrated engine firing of the liquid-fueled Hadley engine, a full-scale prototype of the engine that will propel GOLauncher1, which in October the U.S. Air Force designated as the X-60A. This liquid-fueled, hypersonic testbed vehicle is in development by Generation Orbit for the AFRL in Ohio. The vehicle is designed to provide affordable and regular access to high dynamic pressure flight conditions between Mach 5 and Mach 8 to a wide range of payloads for fundamental research and technology development. The first flight is planned for late 2019.

In October, **the Air Force's Arnold Engineering Development Complex, AEDC, stood up a new branch specifically to coordinate hypersonic activities**. This new organization will coordinate hypersonic tests and maintain execution authority for the Hypersonic Test and Evaluation Investment Program and the High Speed Systems Test Technology program. The organization also was assigned as the lead developmental test organization authority for all Air Force hypersonic programs. Also, significant AEDC facility improvements were completed this year or were scheduled to be completed. A Mach 18 (approximate) test capability was to be established at the Hypervelocity Wind Tunnel 9 at AEDC's White Oak facility in Maryland by December. A new air breathing high Mach capability was established at AEDC in Tennessee. Also, the performance envelope was expanded at AEDC's arc jet facilities.

In Europe, the German Aerospace Center, **DLR, completed a static firing test of an instrumented ceramic matrix composite nozzle with an extension made of carbon fiber reinforced polymer under a project called ATEK, a German acronym for space propulsion technologies for small launchers**. Also in Germany, in September, the DLR started tests in the High Enthalpy Shock Tunnel Göttingen on a 1:2.5-scale model of the glide vehicle in development under Europe's High Speed Experimental Fly Vehicles-International initiative, or HEXAFLY-INT. This vehicle will investigate surface imperfections on hypersonic boundary layer transition. In June, the Italian Space Agency's Italian Re-Entry Nacelle program validated a low-ballistic coefficient, deployable heat shield in the CIRA SCIROCCO plasma wind tunnel, with flight tests to follow in 2019. CIRA in partnership with AFRL completed first prototype demonstrations of Ultra-High-Temperature Ceramic coatings in May. The European Commission-funded Stratofly project started in 2018 to investigate the feasibility of high-speed passenger flight at stratospheric altitudes.

Turning to Asia, **the Japan Aerospace Exploration Agency, JAXA, completed a hypersonic campaign in its Chofu HWT2 tunnel for the development of its H-2 Transfer Vehicle Small Re-entry Capsule**. The measured aerodynamic characteristics of the reaction control system gas-jet interactions agreed well with computations. In September, the HTV and capsule berthed at the International Space Station. Meanwhile, the results of wind tunnel tests on the MoDKI scramjet showed that margins were met for three-component aerodynamic coefficients longitudinal stability at Mach 6.7. In August, the China Academy of Aerospace conducted its first successful flight of the Xingkong-2 or "Starry Sky-2," according to Fox News, marking China's first disclosure of work on a waverider design. The flight has fueled defense research outside of China, because a waverider may challenge current anti-missile systems, designed to protect against slower cruise and ballistic missiles.★

Japan Aerospace Exploration Agency, JAXZ

▶ **Japan tested its super**sonic combustion ramjet MoDKI in the Kakuda wind tunnel this year. MoDKI stands for Model of Demonstration Kakuda Initiative.

Contributors: *Barry Hellman, AFRL; A.J. Piplica, Generation Orbit; Bayindir H. Saracoglu, Von Karman Institute; Alexander Wagner, the German Aerospace Center, DLR; Ali Guelhan, DLR; Wolfgang Jung, DLR; Tanno Hideyuki, JAXA; Dan Marren, Arnold Engineering Development Complex; Raffaele Savino, University of Naples Federico II*

Editor's note: *U.S. Air Force Capt. Travis Odom is a hypersonics research engineer at Wright-Patterson Air Force Base, Ohio. Greg Johnston is a hypersonic flight test lead.*

Luxury ecotourism airship images excite media

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.

The highest-profile airship in the world, Hybrid Air Vehicles' Airlander 10, scored a public relations coup at the Farnborough International Airshow in July — a remarkable achievement considering the craft had accidentally been destroyed eight months earlier.

Like its rival, Lockheed Martin's LMH-1, Airlander 10 is a hybrid airship, meaning it derives part of its lift from helium and the rest from aerodynamics. On the morning of Nov. 18, 2017, however, it derived lift from neither. Sitting uncrewed on the ground at its base in Cardington, England, a gust of wind detached it from its moorings, triggering an automatic deflation system that resulted in damage so significant as to render Airlander beyond repair. The company is moving forward with the design of a production model. In October, the European Aviation Safety Agency awarded Hybrid Air Vehicles, or HAV, a Design Organization Approval, which gives it permission to undertake a flight test program leading to type certification.

HAV at Farnborough displayed artists' conceptions of what Airlander 10's cabin might look like configured for luxury ecotourism. Depicted amenities included a glass-floored observation lounge, a bar and private bedrooms for 20 travelers. The images received media coverage wider and more positive than any airship-related development in decades. HAV attributes the response to public interest in green air travel. Quiet, fuel-efficient airships could indeed allow travelers to reach remote, environmentally sensitive destinations, while leaving a carbon footprint smaller than that of any other aircraft. Airships' large surface areas, combined with recent advancements in photovoltaic coatings and lightweight batteries, mean that solar, all-electric propulsion should be a near-term reality.

In September, France's Hybrid Air Freighters and Oregon's Columbia Helicopters announced they jointly will operate up to 12 Lockheed Martin LMH-1 hybrid airships, which Hybrid Air Freighters had in 2017 agreed to buy. The partners expect to have their first LMH-1 in service in 2020 or 2021 to industrial clients needing the airship's 20-ton lift capability.

In August, **Goodyear christened the third and last of its Zeppelin NTs "Wingfoot Three."** At its base in Carson, California, in December 2017, Goodyear erected an inflatable hangar — the largest structure of its kind in North America — made by Lindstrand Technologies.

Shaanxi Geotime General Aviation Co. of China in June unveiled a 26-passenger rigid airship intended for domestic tourism, the GTGA-K9000. Separately in 2018, China's Ministry of Science and Technology and conglomerate Aviation Industry Corp. of China became lead investors in Flying Whales, a French company that has raised more than $246 million to build a 500-foot rigid airship with hybrid electrical propulsion. The LCA60T would carry 60 tons of timber or other outsized cargo. Flying Whales plans an initial public offering for 2021, to coincide with the flight of its first prototype.

In August, Brazilian aerostat-maker **Altave demonstrated a new version of its tethered military surveillance balloon, Horizonte,** at Brazilian army headquarters in Brasilia. The company also received a U.S. patent for a portable, lightweight winching and anchoring system for tethered aerostats.

Though large new deposits of helium were discovered two years ago in Tanzania, they have not yet come to market. In 2018, world demand (8 billion cubic feet) exceeded supply, and helium's price hit an all-time high of $119 per 1,000 cubic feet.

On Aug. 10, the 150th anniversary of the birth of Dr. Hugo Eckener, the "Magellan of the Air" and skipper of the Graf Zeppelin's around-the-world flight of 1929, a Zeppelin NT overflew his grave in Germany. ★

Hybrid Air Vehicles and Design Q

▼ **Artists' conceptions of** amenities that passengers might someday enjoy aboard an ecotourist luxury airship went viral in 2018. Depicted here: the glass-bottomed observation lounge of Hybrid Air Vehicles' Airlander 10, as imagined by English design consultancy Design Q.


Airbus

The year of electric-powered lift

BY ERASMO PIÑERO JR.

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

▲ The electric-powered Airbus A³ Vahana tilt-wing vertical takeoff and landing aircraft on its first flight in January.

For the better part of 2018, electric-powered flying machines drew the attention of trade publications, well-established aerospace companies, startups and the public at large.

At the second Uber Elevate summit in May, Uber again promoted the need for an electric-powered vertical or short takeoff and landing, or VSTOL, air taxi aircraft that would extend the reach of its ground-bound brethren. Although the concept of air taxis crisscrossing the skies of major world cities has been deemed the stuff of science fiction for years, such a perception may be coming to an end, according to engineers and scientists working on the issue.

This year **NASA increased its involvement in "electrical" conventional takeoff and landing and electrical vertical takeoff and landing, or eVTOL, research with the introduction of its urban air mobility, or UAM**, initiative in May. Under this program, NASA is providing research data from its own X-57 project to industry. In September, the agency announced it would host a series of UAM Grand Challenges to solicit solutions to "foundational UAM ecosystem-wide safety and integration barriers."

Private industry tested other UAM concepts this year, including the 745-kilogram self-piloted eVTOL tilt-wing Airbus A³ Vahana, which completed its first flight in January, and the two-place/self-piloted Lift + Cruise Kitty Hawk Cora prototype, which flew for the first time in November 2017 (at Kitty Hawk's testing facility in New Zealand). Details from their flight test programs remain closely guarded.

News from the electric-powered lift world could not eclipse stories of four Lockheed Martin F-35B Lightning II aircraft arriving in June at Royal Air Force base Marham in England. Their arrival, after a 6,400-kilometer transatlantic formation flight, allowed their participation in the 100th anniversary celebrations of the Royal Air Force a month later. Three F-35Bs performed a low-level flyby above the crowds celebrating in the British capital July 10. The Royal Navy also had reasons to celebrate. On Sept. 25, two F-35Bs landed for the first time on the decks of the British aircraft carrier HMS Queen Elizabeth. This deployment off the U.S. East Coast using U.S.-based F-35Bs was to hone the skills of British sailors operating their new VSTOL jets on their newest aircraft carrier.

In other F-35B-related news, this past March, U.S. Marine Corps Fighter Attack Squadron 121 flew aboard the amphibious assault ship USS Wasp on its first operational deployment, which included operations in the East China Sea.

Lockheed Martin-Sikorsky's S-97 Raider restarted flight testing in June, and construction of the larger Sikorsky-Boeing SB >1 Defiant began this year. Prototypes of the S-97 (a rigid coaxial rotor and compound design) and the SB>1 are part of the U.S. Army Joint-Multi Role Technology Demonstrator program. In Amarillo, Texas, the Bell V-280 Valor tilt-rotor demonstrator flew envelope expansion milestones — flights with zero pylon angles and landing gear retracted. Testing of the V-280 continues at its new home base at Bell's Flight Research Center in Arlington, Texas.

In Europe, **Leonardo announced that the Era Group was the launch customer for the AW609 tilt-rotor aircraft**. The AW609 restarted its test flight program in 2016 with the intent of full European civil aviation certification by year's end. Upon certification, the AW609 will be the first transport category tilt-rotor entering service in 2019.

The Bell Boeing team received a long-awaited contract for supplying the U.S. Navy with carrier onboard delivery replacement aircraft in the form of 44 CMV-22B tilt-rotor aircraft, expected to begin operations in 2021. ★

Editor's note: *Erasmo Piñero Jr. works at Bell.*

Industry disruption, transformation continue into fourth year

BY TOM BUTASH

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

SpaceX

▲ **Reusing rocket components,** like the two SpaceX Falcon Heavy side boosters that landed in Florida in February, promises dramatic reductions in launch costs for the communications satellite industry. SpaceX recovered two of three boosters in the Falcon Heavy's debut. The center core rocket was lost at sea when its drone-ship landing failed.

In many communications satellite service markets this year, operators were again faced with overcapacity and declining revenues, uncertainties about future demand, and ascertaining the best system architectures to serve that indeterminable demand.

Operators were further challenged by the prospect of at least 15 planned non-geosynchronous orbit, or NGSO, constellations of communications smallsats (satellite mass under 800 kilograms) promising increased capacity with universal broadband access at reduced costs and a surfeit of New Space companies developing low-cost smallsat launch vehicles to orbit those constellations. Operators chose to curtail orders for large geosynchronous orbit, or GSO, communications satellites for the fourth consecutive year. In turn, industry manufacturers responded by increasing their focus on and investments in smallsat development and production capabilities.

In March, **Northern Sky Research reported capacity prices had declined 35 to 60 percent** over the preceding two years — and were still dropping — depending on the application. The price declines were attributed, in part, to relentless launches of high throughput satellites. Despite falling capacity prices and the high-profile financial failures of NGSO constellations developed in the late 1990s, investors and innovators — apparently encouraged by another two decades of Moore's law advances in space and substantial reductions in launch costs — are planning new NGSO broadband constellations. Among them are 13 low Earth orbit smallsat megaconstellations, including those from OneWeb, SpaceX's Starlink, Telesat LEO, LeoSat, Facebook's Athena, Boeing V-Band and Samsung, each with between 108 and 4,600 smallsats; and two medium Earth orbit constellations, O3b and ViaSat with 27 and 24 satellites, respectively. Large GSO satellite operators Intelsat, SES, Telesat, Hughes Network Systems, Hipasat, SKY Perfect JSAT and ViaSat invested in NGSO communications satellite constellations, while operators collectively reduced GSO orders for the fourth consecutive year. After averaging 26 GSOs per year over the three years (2012-2014) preceding the downturn, only 19, 15 and eight orders were seen in 2015, 2016 and 2017, respectively. As of mid-September, six competitive orders had been received: one each to Northrop Grumman Innovation Systems (formerly Orbital ATK), SSL, Thales Alenia Space and Israel Aerospace Industries and two to ADS, suggesting a yearend total of eight GSO satellite orders. Some industry pundits believe the annual GSO orders run rate has bottomed and will plateau at this level, with no foreseeable recovery.

In response, **virtually all communications satellite systems manufacturers increased their smallsat development and production capabilities to meet the growing demand for NGSO systems**. In June, Northrop Grumman acquired Orbital ATK. In August, Boeing acquired Millennium Space Systems, and Lockheed Martin invested in Terran Orbital. Also that month, Maxar/SSL announced the opening of its San Jose, California, smallsat development facility while "considering strategic alternatives" for its GSO operations. ADS and TAS refined their smallsat NGSO capabilities with continued work on OneWeb, Iridium and Globalstar, respectively.

SpaceX continued to lead the launch vehicle industry with headline accomplishments. Through mid-October, Falcon 9 had launched 16 flights this year. The latest Block 5 upgrade, which flew three times in July and August, employs a reusable booster stage that can be flown 10 times before requiring significant refurbishment. Falcon Heavy made its debut in February when it launched Elon Musk's red Tesla Roadster into a heliocentric orbit beyond Mars. .

Perhaps inspired by SpaceX's successes, more than 50 New Space companies are developing smallsat launch vehicles, many incorporating reusable boosters. Rocket Lab's Electron, EXOS Aerospace's SARGE, Firefly Aerospace's Alpha and nearly a half dozen privately funded Chinese smallsat launch vehicle companies had rocket launches scheduled before 2019. ★

Contributors: *Chris Hoeber and Roger Rusch*

Ensuring security while building faster supercomputers

BY RICK KWAN

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

Oak Ridge National Laboratory/Carlos Jones

▲ **The Summit** supercomputer at Oak Ridge National Laboratory in Tennessee is the world's most powerful scientific computer.

Whether or not semiconductor technology has reached the limits of Moore's law, the way forward in computing is massive, highly orchestrated parallelism. On the ground, it enables researchers to push the boundaries of energy, advanced materials, artificial intelligence, biology and more. In flight, it enables vehicle or payload autonomy, with increased awareness of surroundings and better real-time decision-making. However, designers need to be careful that clever advances in performance don't result in architectural holes that can breach security, as was reported this year.

In June, **the U.S. Department of Energy's Oak Ridge National Laboratory in Tennessee unveiled the Summit supercomputer as the world's most powerful and smartest scientific supercomputer**. It immediately led the Top500 supercomputer list with a High Performance Linpack, or HPL, rating of 122.3 petaflops (thousand million million floating point operations per second). For certain scientific applications, it will exceed 3.3 exaops (billion billion mixed precision calculations per second). Summit is composed of 4,608 compute nodes, each with two 22-core IBM Power9 processors and six NVIDIA Tesla V100 graphic processing units, or GPUs. Each Tesla V100 has 5,120 CUDA GPU cores and 640 Tensor matrix-processing cores.

The prior top supercomputer, Sunway TaihuLight, developed by China's National Research Center of Parallel Computer Engineering and Technology, became No. 2 on the Top500 list, with an HPL rating of 93 petaflops. No. 3 was Sierra at the Department of Energy's Lawrence Livermore National Lab. It delivered 71.6 petaflops on HPL. Its architecture is similar to Summit; it has 4,320 compute notes, each with two IBM Power9 CPUs plus four NVIDIA Tesla V100 GPUs.

Advanced mobile systems require a mixture of sensor, computing and radio frequency technologies and are limited by size, weight and power. These typically use different types of semiconductors, e.g., gallium arsenide, complementary metal-oxide semiconductor or p-doped MOS. DARPA is trying to bring together existing designs in these different technologies through its CHIPS program, short for Common Heterogeneous Integration and Intellectual Property Reuse Strategies. **Rather than fabricating a chip in a single technology, CHIPS intends to integrate chiplets from different technologies into a single physical package.**

A major hurdle in the CHIPS program is interconnection between the different chiplets. At the DARPA Electronics Resurgence Initiative Summit in July, Intel announced it would provide a royalty-free license to its Advanced Interface Bus to CHIPS participants and others. The company is already applying this with its 8th Gen Intel Core, Radeon Graphics and Stratix field-programmable gate array.

The summit also introduced a couple of projects aimed at realizing a 24-hour design for defense-related hardware. One, known as the Intelligent Design of Electronic Assets program, aims for a "no human in the loop" layout generator to be developed by Cadence and several partners. Another, known as POSH Open Source Hardware, aims to help democratize access to custom, high performance systems on chips through open-source IP.

The microarchitecture of high performance processors came under attack this year, causing microprocessor vendors to issue urgent patches and redesign parts of chips due out later this year. In January, exploits Spectre and Meltdown were reported; variants followed in later months. The exploits affect several generations of products and affect the "speculative execution" pipeline in computers ranging from servers to smartphones. One way to stop them is to turn off out-of-order execution; but this dramatically impacts performance.

Simpler processors like microcontrollers, which typically talk to sensors and controllers, are largely unaffected. Similarly, advanced GPUs used for machine learning get their speed from many identical compute cores rather than heavy pipelining. Conversely, functions such as object identification and vehicle autonomy utilize the types of processor currently affected. ★

UH-1 Huey flies autonomous resupply mission in test

BY NATASHA NEOGI

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

This year yielded many innovations in the field of intelligent systems, including unmanned aerial systems, or UAS. Aurora's Autonomous Aerial Cargo Utility System, or AACUS, participated in U.S. Marine Corps Integrated Training Exercise 3-18 at Marine Corps Air Ground Combat Center at Twenty-Nine Palms, California, in May. As part of the Marine Corps Warfighting Laboratory Expeditionary Hybrid Logistics experiment in conjunction with the exercise, an AACUS-enabled UH-1 Huey helicopter completed the first autonomous point-to-point cargo resupply mission. AACUS was developed for the Office of Naval Research in response to a U.S. Marine Corps Cargo UAS Urgent Needs Statement. AACUS is a rotary wing mission system kit that enables intelligent autonomous tactical flight missions into and out of unprepared landing zones. The program performed cargo/utility missions at its capstone demonstration at Marine Corps Base Quantico, Virginia, in December 2017.

Also throughout the year, the Vehicle Systems & Control Laboratory at Texas A&M University **flight-demonstrated a machine learning algorithm for UAS to visually track stationary and moving ground targets**. Performance of the system was demonstrated starting in December 2017 and continued in July and August with flight test cases of stationary, randomly moving targets and randomly moving targets in unstructured environments in College Station, Texas. Visual tracking of ground targets using UAS is challenging when the camera is strapped down or fixed to the airframe without a pan-and-tilt capability, rather than gimbaled, because the entire vehicle must be steered to orient the camera field of view. This is made more difficult when the target follows an unpredictable path. The tracking algorithm is based on Q-learning, and the agent determines a control policy for vehicle orientation and flight path such that a target can be tracked in the image frame of the camera without the need for operator input.

This year has seen significant accomplishments in intelligent systems for robotic space science and exploration. NASA's Jet Propulsion Laboratory deployed artificial intelligence and machine learning capabilities in support of solar system and Earth science missions. In one prominent application, which began in December 2017 and continued through this year, **convolutional neural networks were trained to classify images of Mars by their content**. One classifier detects craters, dark slope streaks and sand dunes in orbital images; another classifier recognizes different parts of the Mars Science Laboratory's Curiosity rover in its own images. The classifications provide the first content-based search capability for NASA images, enabling users to quickly drill down to images of interest (e.g., monitoring rover wheel condition). The content-based search technology was deployed on the Planetary Data System Atlas website in December 2017.

Similarly, artificial intelligence is being used to automatically schedule the Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station, or ECOSTRESS, science observations. The scheduler generates the instrument command sequences from science campaign priorities and predicted ephemeris without human inputs. The scheduler incorporates visibility, data volume, timing uncertainty and South Atlantic Anomaly operations constraints. ECOSTRESS launched in June, and the AI scheduling went operational in August. ★

▼ A U.S. Marine operates an Autonomous Aerial Cargo Utility System tablet to request an autonomous helicopter delivery, in a test.

Aurora Flight Sciences

Contributors: *Lisa Guerra, John Valasek, Mitch Ingham, Kiri Wagstaff, and Steven Chien*

U.S. military funds major sensor system projects

BY DOMENICO ACCARDO, RAYMOND S. SWANSON AND THOMAS L. FREY JR.

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.

Investments in sensor systems and information fusion for aerospace applications have increased the past several years in part due to new opportunities in the use of drones, networked systems and small satellites, and the U.S. Department of Defense's increased emphasis on artificial intelligence applications.

The DOD is reaping the benefits of its push to incorporate AI and machine learning into operations and products — but not without growing pains. The DOD established the Algorithmic Warfare Cross-Functional Team, or AWCFT, in 2017 to integrate AI and machine learning more effectively across operations. One of the early projects, Project Maven, focuses on applying Google's TensorFlow application program interface to assist in object recognition in unclassified imagery data. In May, Bob Work, a Project Maven founder, said the program is "exceeding my expectations." Also that month, U.S. Air Force Lt. Col. Garry Floyd, deputy chief of the Algorithmic Warfare Cross-Functional Team, said that Maven was active in "five or six" combat locations. Concerns over future uses of the technology forced Google in June to withdraw from participating in any follow-on to Project Maven once the contract expires in 2019.

The Pentagon created the Joint Artificial Intelligence Center in June. It will have oversight of service and defense AI projects over $15 million. It is charged with establishing a common set of AI "standards, tools, shared data, reusable technology, processes and expertise" for the Defense Department.

▼ **An illustration of the** Aladin instrument, a wind lidar, aboard the Aeolus satellite.

European Space Agency

DARPA announced its Artificial Intelligence Exploration program in July to establish a series of "unique funding opportunities" to push the state-of-the-art, focusing on the "third wave" of AI theory. DARPA defines the first wave as rules-based and the second as "statistical learning." The third wave is aimed at machines that can "contextually adapt to changing situations."

In February, **officials at the Air Force Research Lab announced plans for a five-year sensor-fusion program to cost $33.6 million.** The goal of the Precision Real-time Engagement Combat Identification Sensor Exploitation, or PRECISE, project will be to make it easier for troops to identify targets at long ranges. The project's mission is to improve radar technologies that identify air and ground targets for aircraft. The Defense Department announced in October that it had awarded Northrop Grumman a $16.5 million contract for the program.

Researchers at the **University of Waterloo announced in April that they are developing a technology that promises to help radar operators cut through heavy background noise and isolate targets, including stealth aircraft and missiles, with unparalleled accuracy**. Quantum radar uses a sensing technique called quantum illumination to detect and receive information about an object. At its core, it leverages the quantum principle of entanglement in which two photons form a connected, or entangled, pair. This can greatly improve the radar signal-to-noise ratio in certain situations.

NASA launched the Transiting Exoplanet Survey Satellite in April aboard a SpaceX Falcon 9 rocket. TESS has a camera suite composed of four wide field-of-view optical cameras that will be able to monitor a much larger sample of stars compared to its predecessor Kepler. TESS scientists expect the mission will catalog thousands of planet candidates and vastly increase the number of known exoplanets. Of these, approximately 300 are expected to be Earth-sized and super-Earth-sized exoplanets.

On Aug. 22, Airbus launched the European Space Agency's Aeolus satellite on a Vega rocket. The satellite features, the first space-borne light-detection and ranging instrument, which uses the Doppler effect to determine the wind speed at varying altitudes. It will improve the accuracy of numerical weather and climate prediction and advance understanding of tropical dynamics and processes relevant to climate variability. ★

Contributors: *Kent R. Engebretson and J. Chris Aguilar*

Powering InSight, Parker Solar Probe on their missions

BY BARBARA MCKISSOCK

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

▲ **This experimental Stirling engine** has operated at full power for nearly 13 years at NASA's Glenn Research Center in Ohio.

NASA's Parker Solar Probe launched in August and will get as close as 6.16 million kilometers to the sun, into the sun's corona, seven times closer than any other mission. The solar intensity at one point will be 475 times the intensity experienced in Earth orbit. The solar-powered probe uses a carbon-composite heat shield to protect the spacecraft and will contract and extend its solar array wings — which can provide 388 watts at its closest approach — in addition to using active cooling to maintain the arrays at proper operating conditions. The Johns Hopkins Applied Physics Laboratory designed and controls the spacecraft.

The InSight mission to study Mars' interior was launched in May and was scheduled to land in late November. During the cruise phase, the InSight lander is inside a protective aeroshell, which is attached to the cruise stage with its own solar arrays producing approximately 1 kilowatt on Earth and 320 W in Mars orbit at 1.4 astronomical unit. After its approach to Mars, the spacecraft lander will separate from the aeroshell to land. The lander will deploy its own solar arrays on the surface and begin the science phase of the mission, designed to last for approximately two years. InSight is a collaboration between NASA's Jet Propulsion Laboratory and a number of European partners providing the science instruments.

OSIRIS-Rex is scheduled to arrive at the asteroid Bennu in December and start the survey of the asteroid prior to acquiring samples. The spacecraft is powered by two solar panels, each with two-axis tracking, producing 2.7 kW on Earth and 1.2 kW at 1.3 AU during the science phase.

Lockheed Martin's A2100TR satellite bus with 25 kW multimission flexible deployable solar arrays is scheduled to launch in December on Arabsat-6A. It will be the first commercial geosynchronous Earth orbit communications satellite with deployable flexible arrays designed for 15 years of on-orbit operation. The solar arrays deploy into a large surface area for generating power while stowing within smaller stowage volume during launch, as compared with arrays using heritage deployable rigid panels.

Two Multi-Mission Radioisotope Thermoelectric Generators, or RTGs, were delivered to the U.S. Department of Energy's Idaho National Laboratory this year for integration with eight General Purpose Heat Source modules in 2019. Some newly produced plutonium-238 is contained within the modules. It is slated for launch on the Mars 2020 Rover. Also this year, NASA's Next-Generation RTG project was initiated to develop a 400-500 watts electric vacuum-based RTG for use in deep-space missions. This next-generation system seeks to provide performance better than that of the Cassini radioisotope power system.

NASA set a run-time record this year for the operation of a flexure-based free-piston Stirling engine at full power. The experimental unit has performed 110,000 hours (12.5 years) of cumulative operation since 2003, making it the longest-running heat engine in history. Timelines for missions to the outer solar system have durations as long as 17 years, and NASA engineers believe this Stirling design has the potential to meet these life requirements.

NASA's Kilopower project completed nuclear-heated reactor prototype ground tests this year and is being considered for a possible flight technology demonstration mission in the mid-2020s. The ground test was conducted at the Department of Energy's Nevada National Security Site's National Critical Experiment Research Center and is the first test of a U.S. space nuclear power system in over 50 years. The test system was sized for 1 kWatt electric output and featured a 4 kWatt thermal uranium-molybdenum reactor core, sodium heat pipes for heat transfer, and Stirling power convertors developed during the Advanced Stirling Radioisotope Generator program. ★

Contributors: *Steven Geng and Giang Lam*

New thrusters tested; lunar gateway power portion announced

BY TAYLOR SWANSON

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

Many significant achievements in electric propulsion occurred this year, including the development and testing of new thrusters as well as the use of electric propulsion in space missions.

The University of Alabama in Huntsville this year developed and tested a miniature Hall effect thruster with an additively manufactured body, propellant distributor and discharge channel at NASA's Glenn Research Center in Ohio and demonstrated the same performance as conventional miniature Hall effect thrusters but at lower cost and fabrication time.

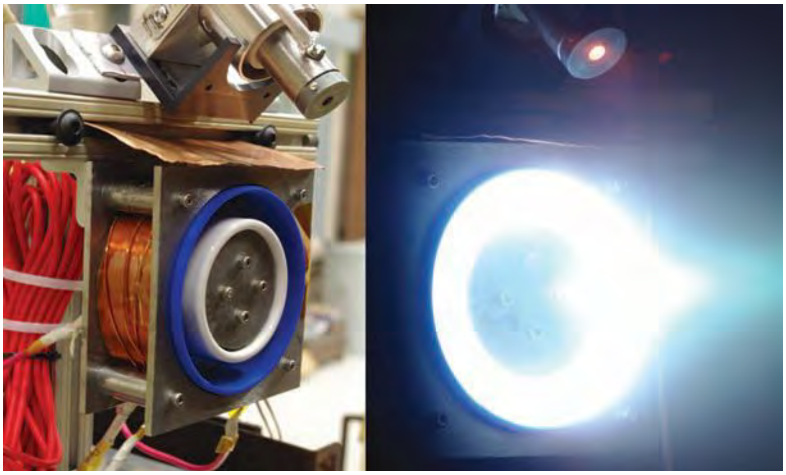
California-based **Phase Four tested radio frequency thrusters for a cubesat and a small satellite** in April and May. These thrusters are electrodeless and thus can be mass produced cost-effectively.

Rafael of Israel's heaterless hollow cathode finished a 5,000-hour endurance test in May. The low-current cathode generated discharge current of 0.8 amperes at mass flow rate of 2.5 standard cubic centimeters per minute and functioned without errors.

NASA used data from low-power tests done in September 2017 of the SSL-made SPT-140 Hall effect thruster to update thruster modeling and trajectory computations and to select thruster operating conditions. The thruster will be used in the Psyche mission, which will explore the metal asteroid thought to be the core of an early-forming protoplanet destroyed by collisions. Psyche will be the first mission to operate Hall thrusters beyond cislunar space.

NASA released a broad agency announcement in September for the power and propulsion element, or PPE, of the Lunar Orbital Platform-Gateway. One solar-powered electric propulsion technology that may be leveraged on PPE is the Advanced Electric Propulsion System, a 14-kilowatt Hall thruster. NASA completed environmental testing in June and completed a 4,000-hour wear test in August of the 12.5-kW Hall Effect Rocket with Magnetic Shielding thrusters to inform the Advanced Electric Propulsion System thruster design.

▼ **The University of** Alabama in Huntsville's miniature Hall effect thruster with additively manufactured components, left, and in operation.



University of Alabama in Huntsville/Gabe Xu

One portion of NASA's Next Space Technologies for Exploration Partnerhips, or NextSTEP, program is high-power electric propulsion. The program requires ground test operation at 100 kW for 100 continuous hours. To prepare for this, Ad Astra Rocket Co. developed key components of its VASIMIR VX-200SS, which accumulated 100 hours in a series of tests concluding in December 2017. Aerojet Rocketdyne's entry in NextSTEP is the X3 Nested Hall Thruster, which had a test scheduled for November.

After the demonstration in 2017 of Busek of Massachusetts' Colloid Micronewton Thrusters, NASA's Jet Propulsion Laboratory and Busek this year continued technology development through the U.S. LISA project. A long-duration test of Busek's BHT-600 thruster began in June using xenon, and alternate propellants including iodine are being investigated.

The Japan Aerospace Exploration Agency's asteroid explorer **Hayabusa2 arrived at its destination, the asteroid Ryugu,** in June. Its primary propulsion is a cluster of four 10 millinewton-class microwave discharge ion engines. The total operation time in the outward journey was 6,515 hours, producing 1,015 meters per second of delta-v, or change in velocity. A model of the microwave discharge neutralizer reached 50,000 hours of diode-mode operation in August.

NASA announced in November that Dawn had gone silent, ending its extended mission orbiting the dwarf planet Ceres. The spacecraft used a xenon-fueled ion propulsion system, IPS, for orbital maneuvers. Since 2007, the IPS has operated for 51,384 hours using 417 kilograms of xenon and provided a delta-v of 11.5 kilometers per second, both world records. In June, the IPS delivered Dawn to its final elliptical orbit with a minimum altitude of about 35 km, allowing the spacecraft to acquire high-resolution data.

Aerojet Rocketdyne's XR-5 Hall thruster system operated for 600 hours to propel Northrop Grumman's Al Yah 3 GEOstar-3 spacecraft to its intended orbit in August, aiding recovery from a January launch insertion anomaly. Aerojet Rocketdyne and ZIN Technologies ion engine passed critical design review for NASA's Evolutionary Xenon Thruster-Commercial project in April. ★

Embracing innovation from Orion to additive manufacturing

BY HARRISON STANKEY AND 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.

U.S. Army

▲ **NASA this year** completed testing to qualify Orion's parachute system for flights with astronauts, checking off an important milestone on the path to sending humans on missions to the moon and beyond.

In September, NASA and its prime contractor Lockheed Martin conducted the final parachute drop test of the Orion spacecraft prior to the 2020 launch of Exploration Mission 1, NASA's uncrewed launch around the moon and back. This drop test was the eighth and final test in a qualification series to validate the system for its upcoming mission, which will once again give humans the capability to travel to the moon. The drop test demonstrated the deployment of Orion's 11 parachutes, preceded by the ejection of the forward bay cover, which protects the parachutes throughout the duration of the mission.

The pyrotechnically actuated thrusters that ejected the forward bay cover were developed by Systima Technologies of Kirkland, Washington. Systima is a company that specializes in the niche of pyrotechnic-driven components that are common in the aerospace industry for mechanisms that require high forces in a small envelope. The propellant within Orion's forward bay cover thrusters generates upward of 115 kilonewtons of force in order to accelerate the 450 kilogram forward bay cover to approximately 13 meters per second in just over half a second.

The drop test demonstrated the systems that will lower the spacecraft and its future explorers back to the ground safely. This critical system will be deployed as Orion re-enters Earth's atmosphere at 11 kilometers per second on its return from visiting the moon.

There were many advances in energetic materials this year overseas in the Netherlands, Spain and Germany.

In June, **TNO, the Netherlands Organization for applied scientific research, began operating a printer that was developed and built in-house for multimaterial gradient printing of gun and rocket propellants, explosives and pyrotechnics**. This was another big step in additive manufacturing, after 2016 when TNO achieved a world first by firing a 30 millimeter shell with 3D-printed gun propellants. That printer, however, was not capable of producing material gradients within the printed objects. Combining the developed energetic materials with the power of functional gradients and 3D printing allows for optimization of performance, flexibility in production and more benign processing conditions. TNO considers this an important improvement compared to classical production methods like extrusion and casting and foresees the first commercial applications in the next five years. TNO has built up extensive experience in additive manufacturing of energetic materials by combining 70 years of energetic material expertise with 20 years of experience in additive manufacturing.

Expal from Spain developed a new safe initiation system, called S-402, that minimizes the risk of an accident as a result of static, erratic or induced currents. Neither can it be initiated by batteries nor by conventional AC sources. The long safety protocols required by conventional electric detonators are not necessary with this digital system. In addition, flexibility, speed of use and low weight/volume of system components are inherent features of this system.

Since the discovery in 2012 of a new energetic molecule, synthesized by a team led by Thomas Klapötke, a professor from the Ludwig-Maximilians Universität in Munich, Germany, the commercial exploitation of this molecule, referred to as TKX50 (dihydroxylammonium 5,5'-bistetrazole-1,1'-diolate), has come a step closer now that Eurenco, Sweden, evaluated its properties in formulations during fiscal 2018. The performance of TKX50 was found to be better than that of Hexogen (RDX) and Octogen (HMX) with a detonation speed that is more than 20 percent higher than that of the currently used explosives. ★

Contributors: *Stephanie Sawhill and Jonathan Beaudoin of Systima Technologies.*
Editor's note: *John F. Zevenbergen is a senior scientist at TNO, the Netherlands Organization.*

Geared turbofan and additive manufacturing among new engine technologies

BY MICHAEL G. LIST

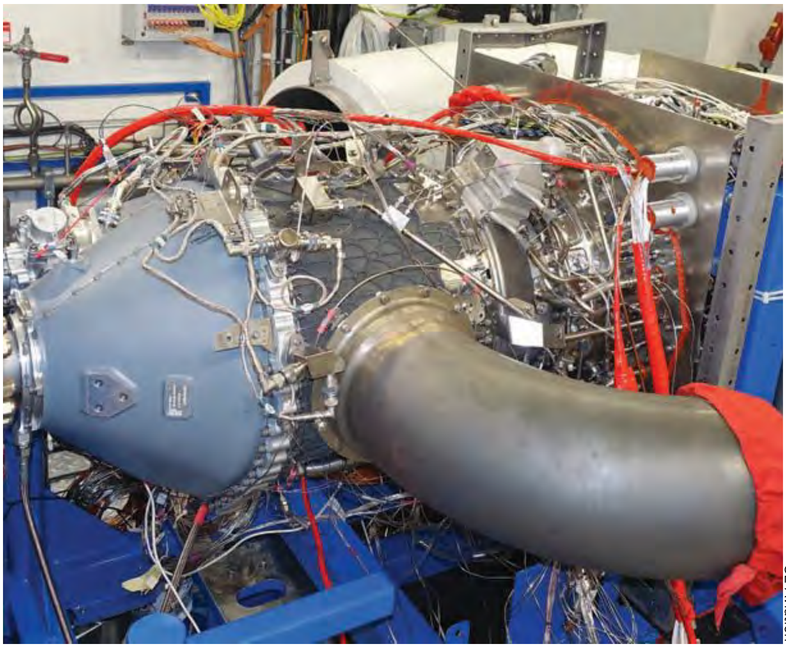
The **Gas Turbine Engines Technical Committee** works to advance the science and technology of aircraft gas turbine engines and engine components.

Engine manufacturers continued a decade-long trend of product introductions, integrating new technologies and manufacturing methods to increase the efficiency and robustness of commercial gas turbine engines.

In April, the GTF, for geared turbofan, PW1900G engine began powering the Embraer E190-E2 for Widerøe Airlines in Norway. The PW1900G is built by Connecticut-based Pratt & Whitney. The engine's geared fan technology reduces fuel burn by 17 percent over the previous-generation E190, with nitrogen oxide emissions 50 percent lower than regulated and noise 17-20 decibels below standards.

Pratt & Whitney announced in July that the FAA granted 180-minute Extended Range Operations certification to its PW1500G engine, which powers the Airbus A220. As GTF production ramps up, the company has instituted a horizontal assembly line for the family of engines to speed production by up to 50 percent versus traditional engine assembly techniques.

In June, Pratt announced the creation of GatorWorks in Florida, describing it as a rapid prototyping facility to cut cost and time to market by 50 percent over traditional military engine development timelines. The new unit incorporates a mix of cross-functional teams, vertical integration and a short list of suppliers and partners.



GE Aviation

▼ **The second GE** Catalyst turboprop engine is installed in a dynamometric test cell at GE Aviation's facility in Prague, Czech Republic.

In March, GE Aviation of Ohio announced the name of its new turboprop engine, the Catalyst, which will power Textron Aviation's Cessna Denali. During the engine design, engineers reduced 855 conventionally manufactured parts to 12 additively manufactured components. Additive manufacturing reduces the Catalyst's weight by 5 percent and contributes 1 percent improvement in specific fuel consumption. The engine ran for the first time in December 2017 at GE Aviation's facility in Prague, Czech Republic, and a second engine ran in June.

The GE9XTM engine lifted off under the wing of GE Aviation's 747 flying testbed in Victorville, California, for its first flight test in March. The GE9X will enter service on the long-range, twin-engine Boeing 777X and is designed to deliver a 10 percent improved aircraft fuel burn versus the 777-300ER. Also in March, GE Aviation GEnx engines powered Australia-based Qantas Airways' first nonstop passenger flight from Perth, Australia, to London, traveling 14,500 kilometers in approximately 17 hours and 20 minutes. The Perth-London flight is the third-longest commercial flight in the world in terms of time.

Rolls-Royce of England showed the Trent XWB-97 engine at the Singapore Airshow in February. The 430,000-newtons-of-thrust engine will exclusively power the Airbus A350-1000. Compared to the 373,650-newtons-of-thrust XWB, the front fan of the XWB-97 will run approximately 6 percent faster, the engine core has been scaled up in size to cope with increased airflow into the compressor, and the combustor and turbines will both run at higher temperatures. The engine also features new materials and coatings for the high-pressure turbine blades as well as an intelligent cooling system to ensure expected performance and efficiency can be delivered at the higher temperatures.

In May, Rolls-Royce announced the launch of the Pearl, a new engine family for business aviation. The engine, developed in Germany and certified in February, will be the sole engine for Bombardier's Global 5500 and 6500 aircraft. The Pearl 15 will deliver up to 67,279 newtons of thrust, deliver up to 9 percent more thrust during takeoff than the BR700, be 2 decibels quieter, and have a 7 percent improvement in specific fuel consumption. The engine was undergoing flight tests that started in January at Bombardier's Flight Test Centre in Kansas. ★

Exploring high-speed propulsion for weapons, passenger aircraft

BY TRAVIS ODOM AND GREG JOHNSTON

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.


Department of Space Indian Space Research Organisation

▶ **A dual mode ramjet** engine (see arrow) was launched in August by a sounding rocket from the Satish Dhawan Space Centre SHAR in Sriharikota, India. The engine ran for five seconds in what Indian officials described as a successful demonstration of key technologies.

Significant research was conducted this year in the U.S. and Asia on air-breathing hypersonic propulsion technologies for high-speed stratospheric flight and improved space access.

Researchers studied ignition in cavity-based flameholders in supersonic flow. Through a collaborative effort among the U.S. Air Force Research Laboratory; the University of Illinois, Urbana-Champaign; and Seoul National University, the spatial and temporal fluctuations of a fueled flowfield were measured through nanosecond-gated laser-induced breakdown spectroscopy. While on average the fuel concentration at a location in the cavity is favorable for ignition, the fluctuations from lean to rich inhibits ignition probability with localized energy deposition. In tandem, experiments at AFRL examined the energy coupling mechanisms of pulse detonation ignition of a scramjet cavity. Multiple measurements showed that a fully coupled detonation entrains greater quantities of high-temperature and reacting fluid in the vortex formed on the edges of the underexpanded detonation plume.

In Europe, **the Stratofly project kicked off in June to investigate the feasibility of high-speed passenger flights at stratospheric altitudes.** The project brings together 10 research establishments from seven countries to address critical challenges for the success of hypersonic passenger aircraft flying at Mach 8. The German Aerospace Center, DLR, this year continued actively pursuing transpiration cooling systems to handle the high wall temperatures and heat loads generated in scramjets. The DLR is conducting experiments to investigate the applicability of transpiration cooling systems in scramjets and the phenomena resulting out of the interaction between a wedge/flameholder and coolant secondary flow. DLR's Institute of Space Propulsion operates a hydrogen/oxygen air vitiator facility at test bench M11.1 in Lampoldshausen that is capable of simulating Mach 5.5 to Mach 8 high-speed flight combustion chamber inlet conditions. Results reported this year showed that the coolant boundary layer is strongly affected by shock-boundary layer interaction and can develop hotspots on the wall due to this interaction, with hydrogen selected as the superior coolant with the fuel ignited by the shock-boundary layer interaction. Furthermore, DLR in collaboration with the Air Force Office of Scientific Research investigated the second generation ultrasonically absorptive thermal protection materials for passive hypersonic boundary layer transition control and thermal protection system application this year. The study was scheduled to conclude with testing of a promising material near Mach 7 flight conditions in the High Enthalpy Shock Tunnel Göttingen.

Turning to Asia, in August **the Indian Space Research Organization conducted its first experimental Mach 6 mission of its hydrogen-fueled scramjet (supersonic combustion ramjet) engine** from Satish Dhawan Space Centre SHAR, Sriharikota. After a flight of about 300 seconds, the vehicle touched down in the Bay of Bengal, approximately 320 kilometers from Sriharikota. The twin scramjet engines were mounted on the back of the second stage for a captive carry flight. Once the second stage reached the conditions for engine "start-up," the scramjet engines ignited and functioned for about five seconds. This flight demonstrated critical technologies such as ignition of air breathing engines at supersonic speed, supersonic flameholding and air intake mechanism. Meanwhile, the Japan Aerospace Exploration Agency, JAXA, designed and fabricated the Himico wind-tunnel model for evaluation prior to the flight test in 2019. ★

Contributors: *Timothy Umbrello, AFRL; Bayindir H. Saracoglu, von Karman Institute; Friedolin Strauss, DLR; Alexander Wagner, DLR; Tanno Hideyuki, JAXA*

Editor's note: *U.S. Air Force Capt. Travis Odom is a hypersonics research engineer at Wright-Patterson Air Force Base, Ohio. Greg Johnston is a hypersonic flight test lead.*

Nammo AS

Toward bigger and better hybrid rockets

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

BY TIMOTHY MARQUARDT AND JOSEPH C. "JOE" MAJDALANI

▲ **A static test of a** record-setting 30 kilonewton hybrid motor at Nammo, the Nordic Ammunition Co., in July. More powerful versions of this motor are being planned to deploy small satellites.

The year was filled with successful hybrid motor test campaigns ranging from the lab bench to the mesosphere. At the NASA-funded Jet Propulsion Lab in California, a polymethyl methacrylate/gaseous oxygen motor that provides approximately 800 meters per second of delta V, or net change in mission velocity, along with attitude control for a 12-unit cubesat was under development. Potential applications for this motor include a Mars orbit insertion with Phobos and Deimos flybys. Over 30 tests were completed by September and preparations for vacuum testing of a flight-like design were underway during the second half of the year. In addition, JPL 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, full scale motor testing of a wax-based fuel with MON-3, a mixed oxide of nitrogen, was carried out in February by Space Propulsion Group Inc. of California and Montana, and Whittinghill Aerospace LLC of California. High performance, stable burns with durations up to 90 seconds were achieved. Moreover, liquid injection thrust vector control testing was performed with direct measurements of side thrust.

Researchers at Purdue University demonstrated the hypergolic ignition and multiple relights of a paraffin-based hybrid motor with sodium amide added to the head end of the grain in a study that began in 2017 and continued through June. The storability properties of the chosen liquid oxidizer, MON-3, combined with the robustness of reliable ignition in the absence of an external energy source, have brought this propellant combination into consideration for future Mars missions. The project is being conducted in partnership with JPL.

In Taiwan, **TiSPACE performed a series of tests in August to investigate the problem of nozzle throat erosion for hybrid rockets with long burn times**. Corresponding tests employed a short section of nylon insert near the aft-end section in the solid grain of a single-port nitrous oxide/styrene butadiene rubber, laboratory-size hybrid rocket motor. The total burn times for these tests were 60 seconds with an average oxidizer to fuel ratio of around 4.6. Results indicated an approximately 60 percent reduction in throat erosion rates when incorporating the nylon insert. Meanwhile, the Advanced Rocket Research Center at National Chiao Tung University in Taiwan leveraged the safety and responsive throttling of hybrid motors with their Quad Hybrid Rocket Engine Levitating Platform. This platform is composed of four fixed, canted nitrous oxide/hydroxyl-terminated polybutadiene hybrid motors mounted to a common airframe. It is controlled by a proportional–integral–derivative algorithm using simple and cheap ball valves to adjust the oxidizer flowrates to each motor. Characterization tests this year showed that this unassuming control scheme is capable of quickly adjusting motor thrust levels with an uncertainty of less than 5 percent.

In Norway, the Nordic Ammunition Co., Nammo, in July completed a static test firing campaign of a hybrid motor that was then used to launch the Nucleus sounding rocket to an altitude of 107 kilometers in September. The 30 kilonewtons of sea-level thrust produced by this motor has set the record for a European-built hybrid motor. More powerful versions of the motor are being planned for small satellite deployment applications. Development is proceeding in partnership with the European Space Agency as part of the Future Launchers Preparatory Program.

Virgin Galactic this year completed three powered test flights of its new SpaceShipTwo vehicle, VSS Unity. The first test, in April, represented the first time that Unity had fired its engines in flight and demonstrated the safe use of an improved "feathering" re-entry system. This test was especially significant as it constituted the first powered flight of a Virgin Galactic spacecraft since a catastrophic accident destroyed the VSS Enterprise in 2014, killing co-pilot Michael Alsbury and injuring pilot Peter Siebold. A follow-up flight in May reached an apogee of 43 km and a maximum speed of Mach 1.9 while a third flight in July extended the performance of SpaceShipTwo to an altitude of 52 km and a Mach number of 2.47. ★

Contributors: *Adrien J. Boiron, Yen-Sen Chen, Ashley C. Karp, Timothée Pourpoint and Jong-Shinn Wu*

Improving simulations of engine performance for training, aircraft design

BY JONATHAN S. LITT

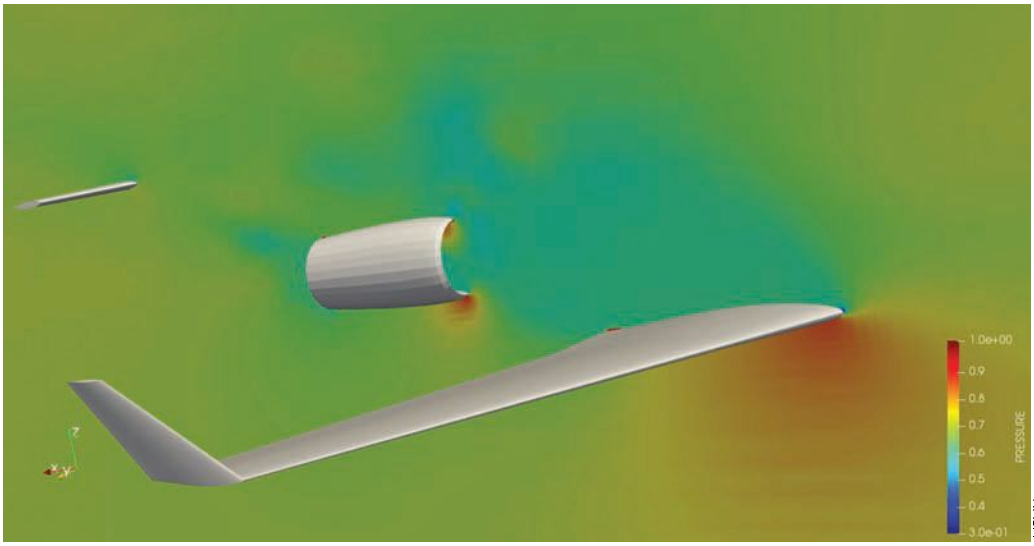
The **Inlets, Nozzles and Propulsion Systems Integration Technical Committee** focuses on the application of mechanical design, fluid mechanics and thermodynamics to the science and technology of air vehicle propulsion and power systems integration.

NASA's Glenn Research Center in Ohio conducted a simulation study of installed jet engine performance at unusual aircraft attitudes, such as those that might be encountered leading up to and during a loss of control event. This sensitivity study was part of the FAA-mandated Safety Enhancement 209, which aims to improve pilot stall recognition and recovery through more realistic simulation of stall events during flight simulator training.

NASA's role in this study was to define aerodynamic model parameters — along with their availability and associated uncertainties — necessary for replicating full-stall flight characteristics of various transport aircraft models. The research focused on a T-tail regional jet aircraft configuration, with the turbofan engines mounted to the fuselage, above and behind the wing. As a result of this positioning, the airflow into the engines has the potential to become distorted as angle of attack, or AOA, and sideslip increase causing the ingestion of wing wake and flow blockage due to the fuselage. To capture this interaction, computational fluid dynamics analysis was used to visualize the total pressure disk at the engine inlet at a variety of altitude, Mach number, AOA, and sideslip conditions; this was completed in September. In October, these total pressure values were used as input to a dynamic parallel compressor turbofan engine model, in which the fan and compressor are each divided into four circumferential segments that extend axially to the bypass nozzle and the combustor, respectively. Simulating the engine with the given inlet conditions provided a way to approximate the effect of inlet distortion and reduced airflow on thrust performance and stability. The use of a dynamic engine model offered the option of regulating either fan speed or engine pressure ratio (the two most commonly controlled variables in turbofan engines) and comparing the results to determine if controller selection causes closed-loop behavior to differ at high AOA and sideslip. The simulation also included the capability to model engine degradation related to use, which has an impact on stability and provides an additional source of uncertainty.

Over the first half of 2018, **the performance and operability of a first-of-its-kind embedded boundary layer ingesting inlet/distortion-tolerant fan, or BLI²DTF, propulsor were established based upon test data acquired in the transonic test section of the 8-foot-by-6-foot Supersonic Wind Tunnel** at Glenn. It was reported in January and further in June, based upon analysis of the test data, that the BLI²DTF propulsor achieved a mass-weighted inlet total pressure recovery from free stream conditions of 96.5 percent and fan stage efficiency of 87.9 percent with nearly 12 percent stability margin. These performance levels support the independently corroborated BLI²DTF system study that identified a five-propulsor fuel burn reduction of 3 to 5 percent and up to 10 percent through the inclusion of additional propulsors to ingest more of the studied commercial hybrid wing body aircraft's boundary layer. Aeromechanics measurements were also reported that established the robustness of the propulsor throughout the matrix of tested conditions as well as through a rapid speed change test sequence. Designed by United Technologies Research Center with contributions from NASA and Virginia Tech as part of a larger program led by NASA, this technology is applicable to a variety of future aircraft types and propulsor installations. ★

***Contributor:** David J. Arend, NASA's Glenn Research Center*



NASA

▼ **This computational** fluid dynamics pressure plot shows the variation in pressure around an aircraft's engine and wing during what would be a potential loss of control event. The flight conditions reflect an angle of attack of 30 degrees, a speed of Mach 0.6 and zero slideslip.

Blue Origin

Hope for sending humans to space again

BY CHRISTOPHER D. RADKE AND VINEET AHUJA

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

▲ **Blue Origin tests** a BE-4 engine in Texas. Two BE-4s will power the booster stage of each United Launch Alliance Vulcan Centaur rocket, the company announced in September.

Liquid propulsion development saw significant progress in support of NASA's Human Exploration and Operations Mission Directorate, commercial launch applications and in-space small thruster engines.

In February, SpaceX's Falcon Heavy, comprised of three Falcon 9 stages, had a near flawless launch and landed both side boosters; the third booster, the core, was lost at sea. The cargo, a Tesla Roadster, was inserted into a heliocentric orbit.

As part of the Space Launch System program, NASA's Stennis Space Center in Mississippi starting in February carried out a series of developmental RS-25 rocket engine hot-fire tests with a new flight controller unit, powering the engine to its highest power level ever. In support of the Exploration Mission-1 flight of the Orion crew and service module, final integration of the flight European service module propulsion subsystem was completed at Airbus in Bremen, Germany, in June. In September, final integration and checkout of the flight crew module reaction control system propulsion subsystem was completed at NASA's Kennedy Space Center in Florida.

NASA's Commercial Crew Program made significant progress. Early in the year, Aerojet Rocketdyne completed delivery of 12 MR-104J engines for Boeing's Crew Space Transportation-100 Starliner spacecraft. In June, **the Crew Dragon capsule for SpaceX's flight test**, Demo-1, was delivered to NASA's Plum Brook Station in Ohio, where it underwent testing in the In-Space Propulsion Facility under simulated high-altitude conditions.

Within NASA's Commercial Resupply Services program, both SpaceX and Northrup Grumman completed flights to the International Space Station. Of note was the reboost of ISS in July by the Northrop Grumman OA-9E Cygnus spacecraft. The 50-second demonstration burn was the first time a U.S. spacecraft has raised the orbit of ISS since the retirement of the space shuttle.

Stennis has also been instrumental in supporting hot-fire testing of other government-sponsored programs, such as DARPA's Experimental Spaceplane and the joint NASA-U.S. Air Force Hydrocarbon Boost technology demonstrator. As part of DARPA's XS quick response engine demonstration, Aerojet Rocketdyne fired its AR-22 booster rocket engine 10 times in 240 hours in June and July, showing the feasibility of rapid recycling of the engine to enable a reusable launch vehicle capable of high-tempo flight operations.

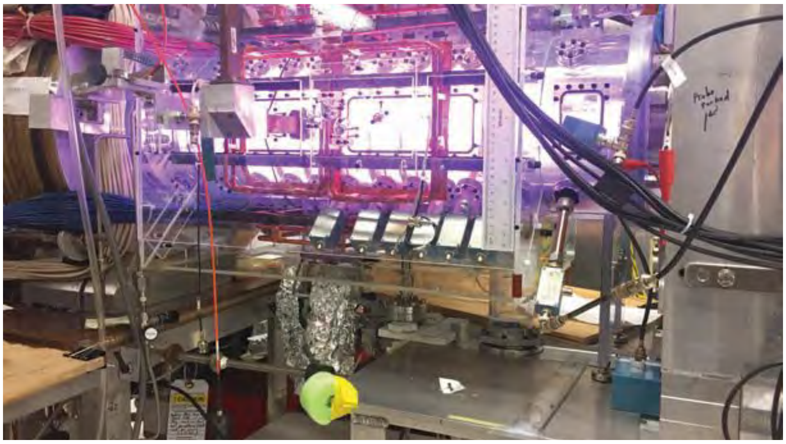
Additionally within the private sector, **Blue Origin continued testing toward completing qualification of its 2,400 kilonewton (550,000 pound-force) BE-4 engine**. In August, the company reported that the new expander cycle design of the oxygen-hydrogen BE-3U upper stage engine had undergone more than 700 seconds of hot-fire testing. Hot-fire testing of Gloyer-Taylor Laboratories' SSE-5k LOX/LCH4 engine verified the predicted high combustion stability margin, clearing the way toward reliable engine scaling and high performance.

In small thruster development, Aerojet Rocketdyne completed hot-fire testing of a new in-space engine designated ISE-100 in May; the engine performed tests representative of potential robotic lunar lander missions and accumulated 75 individual tests, 774 pulses and more than 500 seconds of hot-fire time. Launched in May, NASA's Mars InSight mission incorporated a series of small thruster modules (comprised of Aerojet Rocketdyne's MR-111C and MR-106E thrusters) critical to the cruise phase and atmospheric entry. In addition, there are 12 MR-107N engines, each generating 222 newtons of pulsed thrust to ensure a smooth landing.

In Europe, **Ariane Group continued developing its cryogenic propulsion systems for the European launcher Ariane 6**. The lower stage Vulcain 2.1 engine and the upper stage Vinci engine entered their final qualification campaigns in October and April respectively. In the technology domain, their 100 kilonetwon thrust class Expander Technology Integrated demonstrator for next-generation upper stage engines began a six-month hot-fire test phase.

Also this year, the Japan Aerospace Exploration Agency continued development and testing of its LE-5B-3 and LE-9 engines. ★

Contributors: *David J. Coote, Paul Gloyer, Andy Hoskins, Kevin Lohner, William M. Marshall, Matthieu Masquelet and Dieter Preclik*



Progress made toward nuclear propulsion, in-situ resource utilization

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.

▲ **A Princeton field-**reversed configuration reactor-2 device during a test at Princeton Satellite Systems Inc. in New Jersey.

This year, researchers investigated critical aspects of nuclear thermal rocket propulsion. In this form of propulsion system, hydrogen is heated in a nuclear fission reactor and the hot hydrogen creates thrust, approximately doubling the exhaust velocity compared to the best chemical rocket engine. A team of Aerojet-Rocketdyne, the Ultra Safe Nuclear Corp., NASA and the U.S. Department of Energy expanded the types of design parameters and range of values for the required reactor core of a low enrichment uranium, LEU, nuclear thermal propulsion rocket. These expanded parameters were presented in July at the AIAA Propulsion and Energy Forum to ensure that the best core designs and a wider range of interactions were being captured for later integration into the engine thermodynamic analysis. If the LEU core configuration design parameters are picked arbitrarily based on previous highly enriched uranium designs, LEU configurations will be too heavy, will not achieve criticality for continuous operation, or could have an incorrect power profile and drive up the thermal loads excessively in the engine thermodynamic cycle. Examining many design variables and having well-defined ranges for their values to permit larger combinatorial arrangements and capture critical design interactions. The above-mentioned team conducted a series of detailed analyses to create a performance design map for the most attractive LEU nuclear thermal propulsion engines.

Turning to nuclear fusion, rockets propelled by this technology will create extremely hot plasma with a fusion reaction of deuterium and helium 3. The temperature of this plasma approaches that found at the center of the sun. Powerful magnets contain and then accelerate this plasma for propulsion. **In July, researchers at Princeton Satellite Systems Inc. in New Jersey analyzed numerous fusion engine designs and space mission applications.** One of the designs was a field-reversed, configuration-magnet design for a compact fusion engine. Another was a fusion engine for a fast Pluto mission. Using a multifluid plasma code for direct fusion drive system, exhaust velocity, thrust and efficiency was modeled as function of input power and gas flow. The engine design produced 10,000 seconds of specific impulse, with 5 newtons of thrust per megawatt of generated fusion power.

Many investigations of the natural resources available in the solar system were conducted in the first half of 2018. Lunar, Martian and other solar system resources were assessed by collaborators from the Ultra Safe Nuclear Corp. and a retired Boeing engineer. **Their assessments concluded that without in-situ resource utilization, ISRU, any long-term propulsion architecture is likely unsustainable.** There are vast resources available in space for development and use by future space faring societies. Viable propellant technologies are limited by the accessible resources and will require energy to mine and process. Nuclear power on the planetary surfaces will be crucial for the mining and refining processes. There are multiple architectures for space transportation, with each requiring technology development, access to in-situ resources, power, mass transfer, heat transfer and propellant storage systems. Each of these issues drives the economic sustainability of the ISRU system. Both chemical and nuclear propulsion systems derive many benefits from an optimal ISRU system design.

Very speculative research into anti-gravity was conducted and presented in June. Researchers at the Happy Science University of Japan reviewed historical work on anti-gravity effects, devices and theories. The researchers reviewed the likelihood of anti-gravity propulsion for aerospace applications by using existing experimental data and estimated the possible values of space vehicle specific impulse, delta-V and propellant mass ratio. The preliminary results imply that with a theoretical anti-gravity propulsion system, fuel efficiency improves, the mission cost and flight time can be reduced. Even though technologies for anti-gravity propulsion do not exist, in the near future it may be achieved. Future research will refine their simulations of the lunar flights and further investigate the possibilities of anti-gravity propulsion. ★

Funding increase for pressure gain begins to pay off

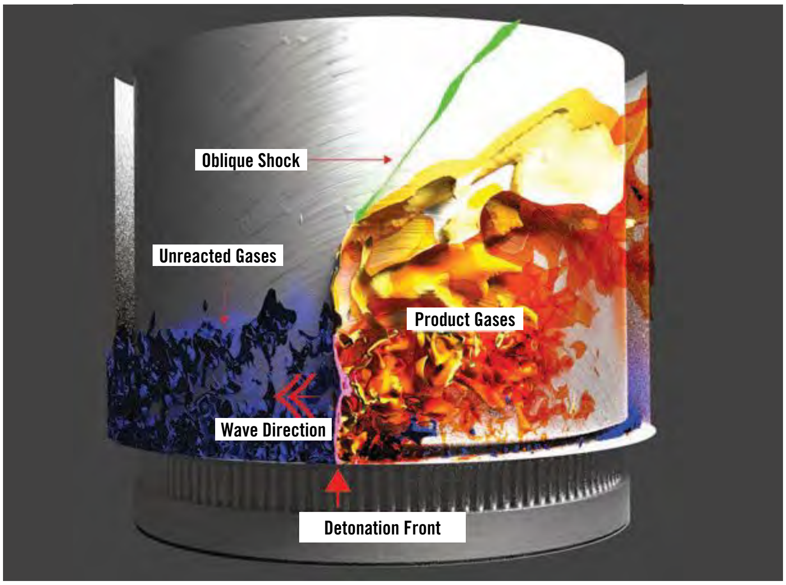
BY DON FERGUSON AND BAYINDIR H. SARACOGLU

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.

Funding for pressure gain combustion research this year fueled a robust growth in effort.

In the U.S., the Department of Energy, Air Force Office of Scientific Research and Office of Naval Research provided a majority of the funding. With these funds, the University of Cincinnati conducted a series of tests to **explore the multimodal operations of annular and "hollow" rotating detonation engines, RDEs,** demonstrating wave speeds greater than 95 percent of the theoretical value and oxide of nitrogen emissions as low as 50 parts per million. At the University of Texas-Arlington, a rig was completed in January to study the impact of swirl and torque in a conventional, annular RDE. The Air Force Research Laboratory, AFRL, and the University of Central Florida independently applied laser absorption spectroscopy to resolve product species, temperature and flow velocity in RDEs, providing previously unavailable detail to the modeling and design communities. Simulations at NASA's Glenn Research Center in Ohio demonstrated increased pressure gain in an Ejector Enhanced Resonant Pulse Combustor concept.

Researchers at the University of Michigan completed a series of tests in April and May using an optically accessible RDE to study the dynamic coupling between reactant injection and detonation resulting in detailed simulations. In a separate activity, the University of Michigan along with University of Central Florida, Purdue University, University of Alabama and Southwest Research Institute collaborated on a Department of Energy funded RDE program with Aerojet Rocketdyne. Four test campaigns were undertaken from February through June to understand the effect of injector design and downstream diffuser configurations on the RDE operation and flowfield, as well as the mapping of the unsteady exit flow using high-speed particle image velocimetry.



University of Michigan

▼ **Experimental and** computational research at the University of Michigan has explored dynamic coupling between reactant injection and detonation utilizing an optically accessible rotating detonation engine resulting in detailed simulations.

Results from an RDC-turbine integration study at the AFRL conducted in January through February suggested minimal performance impact from exhaust flow unsteadiness. Similarly, the Purdue Experimental Turbine Aerothermal Lab presented results in June at the American Society of Mechanical Engineers\International Gas Turbine Institute Turbo Expo on computational studies of new classes of optimized subsonic and supersonic turbines that could tolerate unsteady flow. And in separate programs at Purdue University and AFRL-Edwards, the Air Force Office of Scientific Research provided support for RDE-rocket studies that achieved sustained detonation using hydrogen peroxide/triglyme liquid/liquid propellants.

At Technische Universität Berlin in Germany, with funding from the Federal Ministry of Economic Affairs and Energy, **researchers considered stabilization mechanisms of single and counter-rotating modes on RDE performance**. And in a joint effort among Safran, MBDA Inc. and Institute Pprime in France, researchers focused on the development of a sustained (no reignition) constant volume combustion cycle as well as characterizing detonation in non-uniform fuel-air mixtures. In Russia, Semenov Institute of Chemical Physics experimentally demonstrated continuous-detonation of a n-pentane film in an annular combustor for a rocket application. And at the Institute of Aviation in Poland with funding from the U.S. Air Force, researchers explored the use of gasoline and jet-fuel for air-breathing applications of RDC with a gas turbine.

Yokohama National University, Kyushu Institute of Technology, Sophia University, Saitama University and Tokai University in Japan established a joint collaboration to study an RDE-based gas turbine engine for stationary power generation. Nagoya University, Keio University, Institute of Space and Astronautical Science of Japan Aerospace Exploration Agency, and Muroran Institute of Technology performed system level RDE ground combustion tests in preparation for an upcoming sounding rocket space flight test. ★

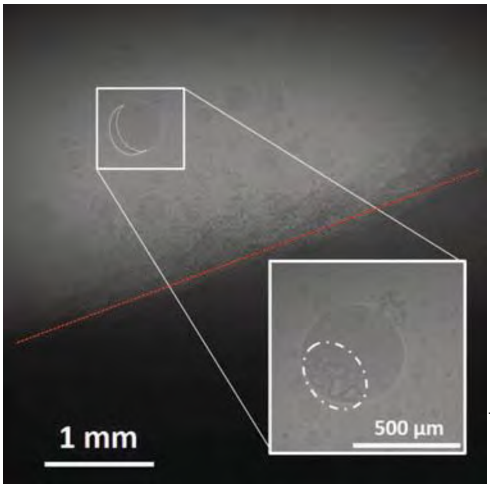
Safely improving jet, rocket fuels

BY JOSHUA HEYNE, HAI WANG AND JOSEPH KALMAN

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.

Significant advancements were made toward the methodology needed for approval of new alternative jet fuels, or AJFs, via the National Jet Fuels Combustion Program, known as NJFCP. These approvals follow a resource-intensive ASTM D4054 fuel standards process in which fuel properties and performance are evaluated for safety, durability and operability. To reduce the cost, fuel volume and time for AJF evaluation, the NJFCP developed new capabilities and understandings of fuel property effects. Results of research conducted at major universities and government facilities have reproduced all known AJF behavior in industry research rigs. Three combustion operability limits, the key to verifying the safe use of AJFs in an engine, are explained via fuel physical-chemical properties. Cold ignition and altitude relight are dominated by a fuel's viscosity and surface tension. In contrast, lean blowout behavior can be controlled not only by physical properties but also by the fuel's chemical reactivity or derived cetane number, which has not been reported previously. These novel operability-property relationships are currently deployed for AJF prescreening and to streamline the ASTM D4054 fuel standards process.

▼ **This radiographic** image shows aluminum particles agglomerating on the propellant surface (indicated by the red dashed line) under a pressure of 6.9 megapascal. The inset highlights the bubbles forming within the particle. The darker region on the highlighted aluminum particle is due to the oxide cap. Published in the October issue of the journal Combustion and Flame.



Joseph Kalman

Focusing on combustion modeling, collaborative efforts among Stanford University, University of Southern California, University of Illinois Chicago and University of Connecticut over the past five years evolved the understanding of real fuel combustion chemistry using the approach of HyChem, for hybrid chemistry. Supported primarily by the Air Force Office of Scientific Research, HyChem was developed on the basis of the separation of fuel pyrolysis and oxidation of the pyrolysis products in the overall combustion process. Thermal decomposition of the fuel is not rate limiting, therefore it can be treated without details at the level of elementary reactions. The HyChem approach treats the reaction kinetics of thermal and oxidative pyrolysis with lumped reaction steps, while oxidation of the pyrolysis fragments is described by a detailed reaction model. The derivation of lumped reaction rate parameters leveraged significant advances in laser diagnostics of multispecies time histories during shock tube experiments. The HyChem approach was tested by the collaborative research team over the year for a wide range of jet and rocket fuels, with the resulting models capable of predicting global combustion properties over a wide range of conditions, including ignition delay, laminar flame speed, and flame extinction strain rate. The approach eliminates the need to use fuel surrogates, a simplification that allows for the reaction model to be reduced to approximately 30 species and perform simulations of real combustors with reduced computational cost.

With an eye toward unravelling the limiting processes and increasing the performance of composite rocket propellants, researchers from California State University, Long Beach; Naval Air Warfare Center Weapons Division; and Argonne National Laboratory in January and February analyzed data from experiments conducted in late 2017. In those experiments, the Advanced Photon Source at Argonne near Chicago was used to conduct X-ray phase contrast imaging of burning solid rocket propellant for the first time. When aluminum particles are added to composite propellants to increase energy density, the particles tend to agglomerate on the surface of the deflagrating propellant, reducing combustion efficiency. Measurements at the Advanced Photon Source provided non-intrusive, in-situ observations of aluminum particle agglomeration at pressures up to 1,000 6.9 megapascal, overcoming decades of attempts to optically diagnose in such harsh environments. The size distribution of aluminum particles on the propellant surface was quantified. Additionally, insight into the metal agglomeration process was achieved with the observation of bubbles forming within the molten aluminum particles, suggesting that polymeric binder used in the composite propellant becomes entrained in the liquid particle and pyrolysizes internally, a process depicted in an image in the October issue of the journal Combustion and Flame. The X-ray images also permitted the observation of aluminum oxide caps forming on the particles, as well as particle coalescence, which will aid modeling work to accurately predict aluminum agglomerate sizes and motor performance. ★

Contributors: *Med Colket, Ronald K. Hanson, Craig T. Bowman, Fokion N. Egolfopoulos, Kenneth Brezinsky, Tianfeng Lu, Andrew R. Demko, Bino Varghese, Katarzyna E. Matusik and Alan L. Kastengren*

▲ **First hot firing of** the P120C motor that will provide first stage propulsion for Vega-C and Ariane 6, at Kourou, French Guiana.

Global competition for affordable heavy lifters

BY JOSEPH C. "JOE" MAJDALANI

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

A United Launch Alliance Delta 4 rocket took off in January from Vandenberg Air Force Base in California to deploy a national defense satellite for the National Reconnaissance Office to low Earth orbit. The rocket was powered by two 60-inch-diameter Graphite Epoxy Motors supplied by Orbital ATK, now Northrop Grumman Innovation Systems. The two 53-foot-long GEM 60 boosters, manufactured in Magna and Clearfield, Utah, burned for approximately 90 seconds while producing 2,490 kilonewtons of thrust. Later in the month, a ULA Atlas 5 launched from Cape Canaveral. The Atlas carried a U.S. Air Force missile-detection satellite. Three other Atlas launches took place in March, April and May, followed by a second Delta 4 launch in August.

On Jan. 31, **Raytheon and Boeing were awarded two major defense contracts.** Raytheon won a $2.3 billion Patriot missile contract from the Pentagon, specifically, to continue servicing its anti-missile program through January 2023. Boeing was awarded $6.56 billion to extend its management of the U.S. missile defense system through 2023, particularly, by continuing to develop and sustain existing ground-based mid-course antiballistic missile systems. As part of this program, Boeing will augment the 44 California- and Alaska-based interceptor networks with 20 additional units. Boeing's subcontractors include Northrop Grumman Innovation Systems, which manufactures the boosters; Raytheon, which builds the hit-to-kill warheads; Northrop Grumman, which delivers the battle management systems; and Aerojet Rocketdyne, which provides the in-flight guidance systems.

On the global stage, the three-year project GRAIL, or Green Advanced High Energy Propellants for Launchers — which the Horizon 2020 European Commission initiated Feb. 1, 2015 — concluded Jan. 31. The project aimed at developing propellants with a reduced chlorine content. The consortium involved industries and research institutes from Sweden, France, Germany and Italy. Through this program, inert and active binders as well as innovative aluminum-based metal fuels were developed and tested. **The feasibility of a cleaner propellant was demonstrated by test firing small-scale motors that matched the ballistic and sensitivity specifications of solid rocket motor boosters.**

In Japan, a 174-foot tall H-2A rocket lifted into the sky above the Tanegashima Space Center on Feb. 27. Its mission was to deploy an information-gathering satellite, or IGS, intended to collect images of North Korea's missile activities and other sites. The rocket's 6,227 kilonewtons of thrust were secured by its hydrogen-oxygen LE-7A main engine and two solid rocket boosters (SRB-A3) that burned for about 115 seconds and produced 2,305 kilonewtons of thrust each. A similar IGS launch via H-2A occurred June 12.

In early March, test-stand qualification tests of Zefiro 40 were conducted at sea level in Sardinia, Italy. This 1,304 kilonewtons-capable motor, prepacked with 36 metric tons of solid propellant, will serve as the second stage of the new Vega C vehicle; its first flight is scheduled for 2019.

The P120C rocket motor, developed jointly by Ariane Group and Avio, was test-fired at the European spaceport in French Guiana in July. It consumed more than 142 metric tons of propellant in under 135 seconds, thus generating 4,448 kilonewtons of thrust. The P120C, the world's most powerful single-segment solid rocket booster, will serve as the first stage of the Vega-C launcher and the strap-on booster for Ariane 6.

Meanwhile, the European Vega rocket launched the Aeolus and PRISMA weather and Earth observation satellites in August. After several launches, Ariane 5, which relies on two P241 solid rocket boosters, overtook its 100th flight targeting the BepiColombo mission to planet Mercury, which is jointly administered by the European Space Agency and the Japan Aerospace Exploration Agency. ★

Contributors: *Michel Berdoyes, Clyde Carr, Filippo Maggi, Agostino Neri and Thomas Williams*

Lightweight fission reactor passes test; work on innovative engine combustor

BY DAVID POSTON, DAVID B. CARRINGTON AND RYO S. AMANO

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.

Los Alamos National Laboratory

Kilopower, a lightweight fission system, passed a key test this year at the Nevada National Security Site. The demonstration was called KRUSTY, short for Kilopower Reactor Using Stirling Technology. This photo shows the fully assembled KRUSTY core.

The Kilopower nuclear power system could enable long-duration crewed missions to the moon, Mars and beyond. In May, NASA announced that this lightweight fission system passed an extensive operating test and performed well under various challenging conditions. The demonstration was called KRUSTY, short for Kilopower Reactor Using Stirling Technology.

Kilopower, which passed tests for nominal and off-normal operating scenarios, is capable of providing up to 10 kilowatts of electrical power — enough to run several average households — continuously for at least 10 years. **Four Kilopower units would provide enough power to establish an outpost for astronauts on Mars.**

The prototype power system contains a solid, cast uranium-235 reactor core, about the size of a paper towel roll. Passive sodium heat pipes transfer reactor heat to high-efficiency Stirling engines, which convert the heat into electricity.

NASA and the U.S. Department of Energy's National Nuclear Security Administration conducted the test at the Los Alamos-led National Criticality Experiments Research Center at the Nevada National Security Site.

"Safe, efficient and plentiful energy will be the key to future robotic and human exploration," said Jim Reuter, NASA's acting associate administrator for the Space Technology Mission Directorate, in a press release.

NASA's Glenn Research Center in Cleveland leads the project in partnership with NASA's Marshall Space Flight Center in Alabama and the National Nuclear Security Administration, including Los Alamos, Nevada National Security Site and Y-12 National Security Complex. "Kilopower gives us the ability to do much higher-power missions, and to explore the shadowed craters of the moon," said Marc Gibson, lead Kilopower engineer at Glenn. "When we start sending astronauts for long stays on the moon and to other planets, that's going to require a new class of power that we've never needed before."

In the turbine engine field, **a team led by the University of Wisconsin-Milwaukee in May began design and development of a gas turbine combustor that will work differently from the combustor in a conventional gas turbine engine.** A turbine engine must typically generate a uniform flow of combustion gases to spin its blades without excessive wear or risk of damage for high-performance in power efficiency in aerospace power propulsion devices. Damaging spikes in temperature and pressure are avoided by allowing the volume of gas to expand, which encourages even deflagration, the term for the rapid burning of the fuel-air mixture as it is sprayed or injected into the combustor. The resulting stream of combustion gases rushes through the engine, spinning turbine blades before it exits. The University of Wisconsin-Milwaukee design will produce a highly uniform temperature and velocity field at the exit of the combustors, before impinging to the gas turbine stator and rotor stages. The idea is to protect the gas turbine rotor and stator components from thermal cracking to keep the engine performance raised over that of existing gas turbine combustor designs.

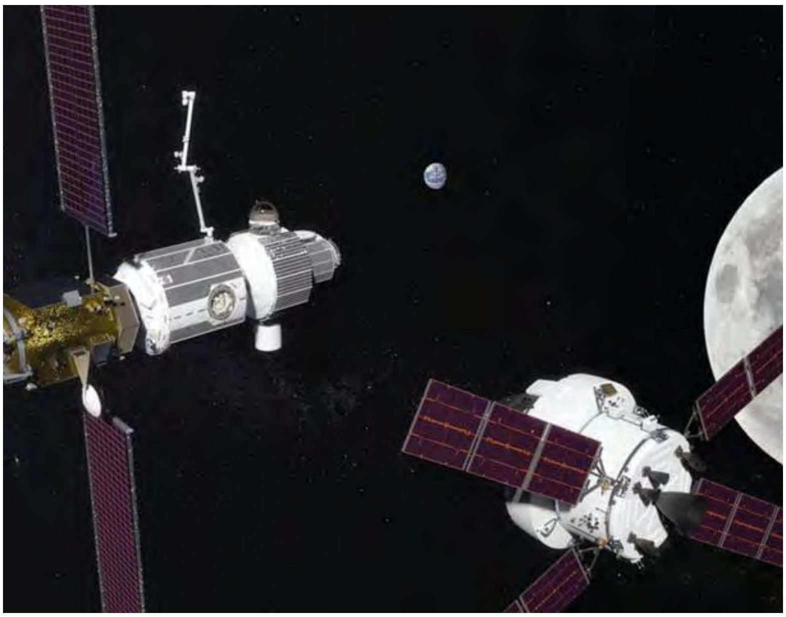
The team's combustor design contains an American football shape body to control the exhaust flow, but one with guide vanes mounted on the surface of the body to cause swirling flow streams. Some significant achievements of the usage of a streamlined shape are examined in staggered holes mixing chamber of the primary hot stream and radial cooling jets. The addition of swirling fins was the primary interest to increase the vorticity in the flow and enhance dispersion. Flow and temperature fields with the seven swirling patterns were analyzed and represented through experimental work and followed computer simulations. ★

Editor's note: *David Poston works at Los Alamos National Laboratory.*

Report links astronauts' increased body temperatures to time in space

BY JONATHAN G. METTS

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



NASA

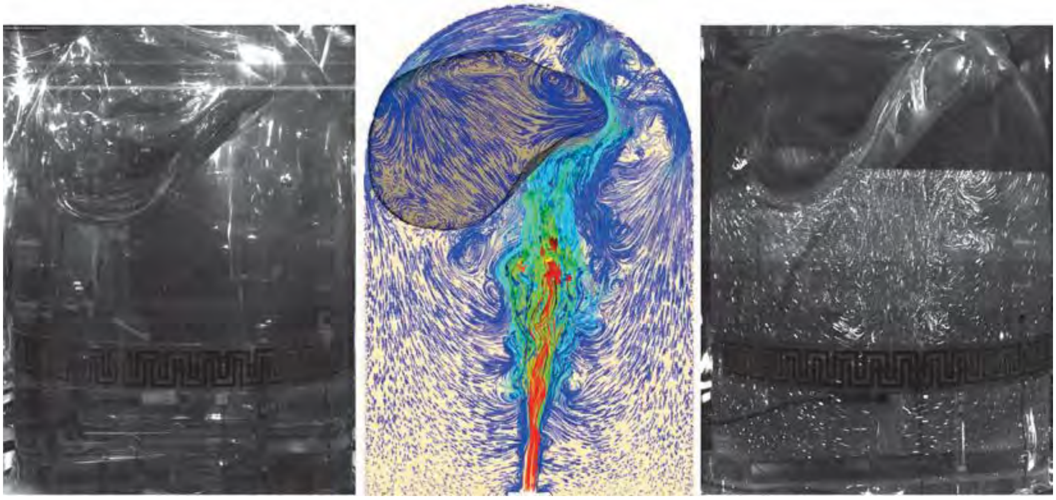
◀ **NASA's Lunar Orbital Platform-Gateway,** in an artist's rendering.
▼ European Space Agency astronaut Samantha Cristoforetti wore a thermometer during some of her time on the International Space Station in 2014-15.

Space fever. Widely reported in January, Nature's Scientific Reports in late 2017 published new research, sponsored by the European Space Agency, that determined spaceflight increases astronauts' core body temperature by 1 degree Celsius and that the change occurs gradually over 2½ months. The findings were based on direct measurements collected by 11 crew members aboard the International Space Station from 2009 to 2013. They used an adhesive sensor that measures both forehead skin temperature and the local air temperature to improve accuracy without more invasive techniques. The astronauts' temperatures were higher in space — both during rest and while exercising on the station — and the effect continued for some time after they returned to Earth.

Fruit fly studies continued on the ISS with the April launch of the latest follow-up to 2015 and 2017 flight experiments, a research program led by NASA's Ames Research Center in California and City College of New York. This latest investigation focuses on the combined effects of spaceflight on innate immunity by studying the host-parasite relationship between fruit flies and Leptopilina wasps. The flies are incubated and housed in vented fly boxes, which provide airflow, visibility and environmental monitoring. Drosophila melanogaster flies are genetically similar to humans, and the research program aims to learn more about the effects of spaceflight on human physiology.

In May, **NASA further defined the Lunar Orbital Platform-Gateway program for the agency's human exploration goals, with plans to launch a power/propulsion module in 2022**, then adding habitation capabilities in 2024 to support crewed missions to the lunar orbital station for as long as 60 days. The broad program folds in the Orion spacecraft and the Space Launch System rocket, while also leveraging NASA's commercial habitat developments through its Next Space Technologies for Exploration Partnerships program and commercial resupply services, as established for the ISS. Initially, crew members would observe the lunar surface and perform telerobotic missions on the surface; a planned airlock upgrade would enable lunar orbital spacewalks.

The ISS' robotic tools are in the fight against breast cancer on Earth. The Image-Guided Automated Robot — based on Canadian company MacDonald, Dettwiler and Associates' CanadArm and DEXTRE robotic arms for in-space maintenance — completed Phase II clinical trials in July. It will provide remotely operated, MRI-guided biopsies to screen for breast cancer at local hospitals lacking access to expert radiologists. ★



A year of space station experiments, commercial launches and education initiatives

BY STEVEN COLLICOTT

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.

▲ **Zero-Boil-Off Tank experiment:** From left, a white-light image, computational fluid dynamics model results, and a particle image velocimetry image depict the fluid flow and deformation of the vapor bubble by a liquid jet during forced-jet mixing pressure control experiments on the space station. Visible is the upper 75 percent of a small-scale fuel tank. The experiment's intended application is to lead to the development of fuel depots on orbit for long-duration interplanetary missions.

NASA, the Center for the Advancement of Science in Space and commercial operations contributed to milestones in the microgravity and space processing field in 2018. The ZBOT, for Zero-Boil-Off Tank, experiment was a high-profile NASA fluids payload on the International Space Station. Creative approaches by the Center for the Advancement of Science in Space, or CASIS, continued to broaden participation in the ISS by increasingly diverse groups. Commercial suborbital spaceflight was led by Blue Origin, which flew many payloads in the last 12 months.

A series of ZBOT tests on the ISS returned large sets of data. ZBOT studies cryogenic propellant processes in weightlessness, including self-pressurization, temperature control, and thermal and two-phase fluid effects of mixing jets for thermal control. In addition to knowledge gained from observations on orbit, many years of substantial ground-based computational fluid dynamics modeling efforts provided for rapid comparisons with flight data. ZBOT was returned to Earth for additional ground-based experimentation.

CASIS again collaborated with the National Science Foundation to solicit proposals for fluids experiments on ISS. **CASIS physical sciences payloads included an experiment to examine the characteristics of freeze-drying, now a common production process on Earth for pharmaceuticals, in weightlessness and a test of continuous separation of immiscible liquids for continuous-flow chemical production processes.** CASIS also involved U.S. high school students with its "Guardians of the Galaxy Space Station Challenge," which solicited experiment proposals on two themes. CASIS announced in May the two experiments selected to fly on the ISS are a test of a misting device for hydrating plants in zero gravity and an evaluation of the efficacy of a dental adhesive when applied in zero gravity.

The commercial reusable suborbital rocket industry continued to develop. Most notably, **Blue Origin flew approximately 25 payloads for customers in 12 months.** Virgin Galactic announced in April that its spaceship Unity had made its first supersonic, rocket-powered flight. The company reported a second test flight in May. Exos Aerospace launched its 50-centimeter-diameter, 10-meter-tall suborbital SARGE rocket for the first time in August at New Mexico Spaceport America. Exos aborted the test flight midway during ascent for what it said was a safety reason. The company said it recovered the rocket with "damage only to sacrificial components."

Blue Origin and NanoRacks offered K-12 classrooms the possibility of sending experiments to space with their "Feather Frame" payload format. Initial K-12 payloads flew in December 2017, including the successful second-grade "Zero-gravity Glow Experiment," which demonstrated firefly glow in zero gravity. For approximately half the cost of high school football uniforms, $8,000, any K-12 school can fly a 2U-sized payload on Blue Origin's New Shepard suborbital rocket. Supporting efforts for this opportunity are emerging, including the nonprofit Arete-STEM Project to assist teachers and the free 2U-sized "Purdue School Launchboxes," which are provided free to teachers to enable them to focus on the education and science in payloads. ★

Longer-range and advanced seekers dominate missile development

BY JEFF SCOTT

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

This year saw continued use of sophisticated missile technology in combat and new developments to address future threats.

In April, the U.S., Britain and France launched 105 cruise missiles against Syria after the repeated use of chemical weapons on civilian populations. The raid marked the combat debut of both Lockheed Martin's Joint Air-to-Surface Standoff Missile, or JASSM, and the French Navy's Missile de Croisière Navale land attack cruise missile developed by MBDA Inc. U.S. Air Force B-1 bombers fired 19 JASSMs while a French warship launched a trio of Missiles de Croisière Navale. The attacks struck facilities that manufacture and store chemical weapons for the Syrian regime. The U.S. Navy also participated by deploying 66 of Raytheon's Tomahawk cruise missiles from a submarine and a pair of surface ships. Additional strikes were made by French and British Storm Shadow standoff cruise missiles launched from Rafale, Tornado and Typhoon fighter jets.

In June, **the U.S. Army approved initial production for the Joint Air-to-Ground Missile after flight tests were completed**. Developed by Lockheed Martin, JAGM adds a dual-mode semi-active laser and millimeter-wave radar seeker to the Hellfire II airframe. The upgrade provides fire-and-forget capability in day or night conditions against stationary or moving land and maritime targets despite bad weather or obscured conditions. JAGM is due to become operational with Army and Marine Corps attack helicopters and unmanned vehicles starting in 2019.

The U.S. Air Force's Small Diameter Bomb II, also dubbed StormBreaker by manufacturer Raytheon, completed developmental tests in April and began operational testing in July. The Small Diameter Bomb II is a glide weapon with a unique tri-mode seeker that employs millimeter wave radar, uncooled imaging infrared and semi-active laser guidance. Combined with a two-way datalink for receiving in-flight updates, the bomb can detect, classify, track and engage long-range stationary or moving targets in adverse weather. Pilots dropped 44 weapons and used all modes of operation during the test program.

In July, **the U.S. Navy announced the first guided flight test of the Evolved SeaSparrow Missile Block 2 ship self-defense weapon**. Block 2 adds a new active radar seeker that allows the Raytheon missile to complete terminal engagements without a launch ship's target illumination radars. This guided shot intercepted a BQM-74E drone and followed two controlled flight tests in 2017. Developed by a 12-nation consortium, the weapon is expected to enter production in 2019 and start fielding in 2020.

In anti-ship warfare technology, the **U.S. Navy awarded a contract in June to Norway's Kongsberg for integrating the Naval Strike Missile aboard littoral combat ships**. The Naval Strike Missile and the Japanese Type 12 surface-to-surface missile also completed live-fire tests at the Rim of the Pacific exercise in Hawaii in July. The U.S. Army and Japan Ground Self-Defense Force showed how both missile types can be launched from the Palletized Load System to demonstrate a shore-based anti-ship capability. Along with several other weapons launched from ships, submarines and aircraft, both the Naval Strike Missile and Type 12 sank a retired warship during the exercise.

A focus of new development is hypersonic weapons capable of traveling at more than five times the speed of sound. Seeking to accelerate research in this field, the U.S. Air Force awarded contracts to Lockheed Martin in April for the Hypersonic Conventional Strike Weapon and in August for the Advanced Rapid Response Weapon. Both systems, expected to field in the early 2020s, are air-launched and boosted to high altitudes by rocket motors before gliding to their surface targets along a high-speed trajectory that makes intercept difficult. ★

▼ **A Naval Strike Missile** launches from a U.S. Army Palletized Load System truck, hitting a decommissioned ship at the Rim of the Pacific exercise.

U.S. Army

Small satellites capable of big science

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.

The small satellite community saw many developments this year, including proposed rules at the Federal Communications Commission to support streamlined frequency licensing; the launch of the first interplanetary cubesats, which were en route to Mars; the inflight demonstration of an optical communication link; and the demonstration of arcsecond level pointing on a cubesat thus enabling cutting-edge astrophysics from a small satellite platform.

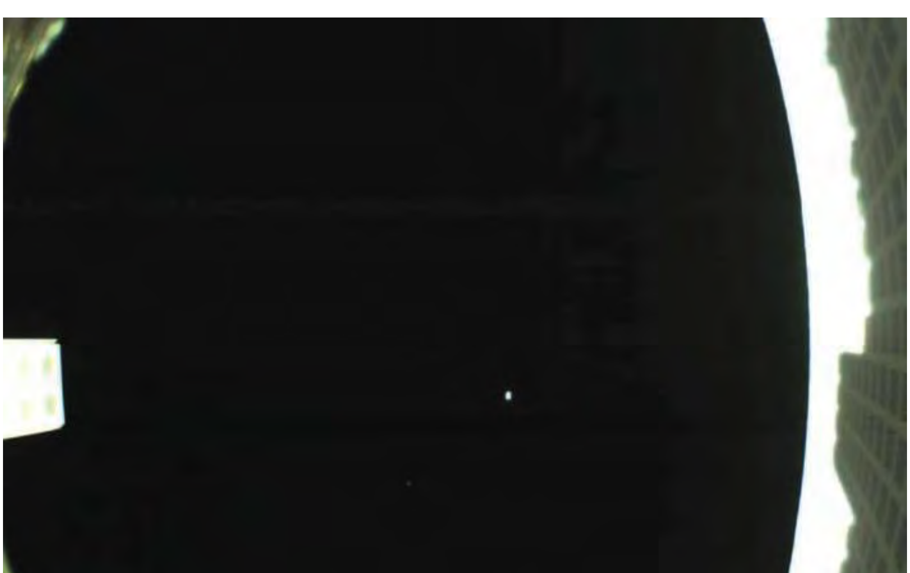
Given the rapid growth of small satellite applications over the past decade, **the FCC issued a Notice of Proposed Rulemaking in April titled "Streamlining Licensing Procedures for Small Satellites."** This process has received significant attention along with official comments from a range of satellite service providers, the Commercial Satellite Spectrum Management Association and a consortium of universities. There is a broad community consensus that a streamlined frequency licensing process will benefit all small satellite operators.

Although NASA is developing more than a dozen interplanetary small satellites, its Mars Cube One (twin 6U cube satellites) can claim to be the first to travel beyond Earth orbit. Free flying alongside the Mars InSight lander, Mars Cube One will serve as the real-time communications relay back to Earth during InSight's crucial entry, descent and landing on the red planet. Mars Cube One had a planned Nov. 26 flyby, but "B" made history of sorts May 9, capturing an iconic picture of the Earth and moon akin to the famous "Pale Blue Dot" image acquired by Voyager 1. While the cubesat's image was from a distance of 1 million kilometers, it was at that time already the farthest a cube satellite had traveled into space. Thirteen additional cubesats are expected to be deployed into lunar orbit from the Space Launch System in June 2020.

It has been nearly 20 years since optical communications were first demonstrated between large satellites and from satellite to ground. Until a few years ago, the power and fine pointing control required put this high bandwidth communication method beyond the reach of small satellites. Developments this year proved that is no longer the case. In April, **the Aerospace Corp. in collaboration with NASA succeeded with the first laser communications between cube satellites with the Optical Communications and Sensor Demonstration**. The demonstration achieved 100 megabits per second, a 50-times increase over similarly sized radio frequency communications, between the co-orbiting AeroCube-7B and -7C. The 1.5U spacecraft had a pointing accuracy of 0.025 degrees, a 40-fold improvement over previous cube satellite benchmarks, by incorporating tiny star trackers.

In a similar vein, **2018 became the year the potential for small satellites as tools for astrophysicists was conclusively demonstrated**. The Arcsecond Space Telescope Enabling Research in Astrophysics, or ASTERIA, built and flown collaboratively by NASA's Jet Propulsion Laboratory and the Massachusetts Institute of Technology, won the Small Satellite Mission of the Year Award on Aug. 9 at the 32nd annual Small Satellite Conference. ASTERIA's science mission of measuring the brightness of stars by precisely staring at them for long periods is done easily by large satellites. However, ASTERIA broke new ground in engineering by miniaturizing optical and thermal sensor fine positioning controls to fit within the size, weight and power constraints of a 6U cube satellite. In February, ASTERIA demonstrated better than 0.5 arcsecond root-mean-square pointing stability over 20 minutes. Among other applications, future small satellite missions will be able to use this technology to assist in identifying exoplanets transiting other stars. ★

Contributor: *Scott Palo*



▼ **The first image from** one of NASA's Mars Cube One cubesats shows the cubesat's unfolded high-gain antenna at right and the Earth, the bright dot.

NASA

Intense focus on NASA's Lunar Orbital Platform-Gateway

BY THEODORE W. HALL, BARBARA IMHOF AND MARIA JOÃO DURÃO

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.

November marked the 20th anniversary of the "groundbreaking" — or breaking away — of the International Space Station. The first module launched in November 1998.

This year was also notable for something that did not happen: The Bigelow Expandable Activity Module was not unberthed and deorbited. Instead, Bigelow Aerospace announced in December 2017 that NASA had awarded it a sole-source contract to extend the life of the module for a minimum of three years.

In February, **Bigelow announced the creation of Bigelow Space Operations, a subsidiary that will operate commercial space stations built by the parent company**. Its first properties will be two B330 modules, each about a third of the pressurized volume of the ISS.

There has been much discussion this year about commercializing the ISS after 2024. NanoRacks announced in April that its space station airlock module "Bishop" had completed a critical design review. Bishop will be the station's first commercial airlock. The Houston-based company says its airlock module will offer five times the satellite deployment volume of current station facilities and that it will be capable of relocating from the current station to a future commercial outpost such as NanoRacks' proposed "Independence 1," formerly known as Ixion.

Axiom Space announced in June that it has partnered with hotel architect Philippe Starck to design its space module interiors. Initial design concepts have been posted on Axiom's and Starck's websites.

The United Kingdom announced at the Farnborough Air Show in July that the government will begin development of Britain's first spaceport in Sutherland, Scotland, with Lockheed Martin as prime contractor.

As low Earth orbit becomes a commercial domain, government agencies are setting their sights on the moon and cislunar space. In May, **NASA published a "Memorandum for the Record" outlining its plans for the Lunar Orbital Platform-Gateway**. In the memo, the 15 space agencies in the International Space Exploration Coordination Group reported their consensus on gateway's importance in expanding human presence in deeper space.

Commercial design concepts under NASA's Next Space Technologies for Exploration Partnerships, or NextSTEP, program are integral to gateway development. In May, NASA announced awards under three tracks to nine companies and one university: Blue Origin, United Launch Alliance, the University of Illinois and UTC Aerospace Systems for identifying gaps associated with in-situ resource utilization; BlazeTech Corp., Paragon Space Development Corp., Skyhaven Systems and Teledyne Energy Systems for component-level development and testing; and Honeybee Robotics Spacecraft Mechanisms Corp. and OxEon Energy for subsystem development and testing. At the Kennedy Space Center in August, Lockheed Martin exhibited its prototype for a deep-space habitat. Other habitat contractors include Boeing, Sierra Nevada Corp., Northrop Grumman Innovation Systems, NanoRacks and Bigelow.

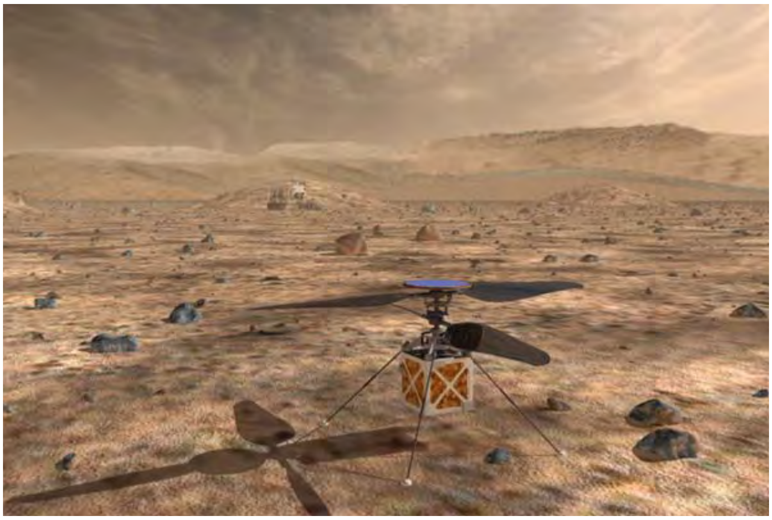
In July, **the European Space Agency commenced activities for the European contribution to gateway, focused on the airlock and the habitation module, with two parallel studies for each to build and test demonstrators.** Prime contractors include Thales Alenia, Airbus and Space Applications Services. Liquifer Systems Group is the architectural subcontractor for the Airbus team.

The German Aerospace Center announced in April the first harvest in the EDEN ISS experimental greenhouse, which began relocation last year to the Neumayer Station III in Antarctica. It arrived there in January. ★

Editor's note: Barbara Imhof works with Liquifer Systems Group.

▼ **The EDEN ISS** experimental greenhouse at the Neumayer Station III in Antarctica is testing methods of cultivating produce for onboard the International Space Station and long-term missions in space.

DLR, the German Aerospace Center


NASA

Busy year of testing, robotic operations

BY JIAN-FENG SHI, KATHERINE STAMBAUGH 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.

▲ **The Mars Helicopter,** seen in a screen grab from an animated video, will travel with the Mars 2020 rover. The Mars Helicopter flights will be the first controlled heavier-than-air flight outside the Earth atmosphere.

NASA's Johnson Space Center's Robonaut 2 hitched a ride from the International Space Station back to Earth in May on a SpaceX Dragon spacecraft. NASA engineers discovered a fault in Robonaut's grounding connection from its computer chassis.

A new "crew member" made from 3D-printed metal and plastic arrived on the ISS in June. The Crew Interactive Mobile Companion, or CIMON — provided by the German Aerospace Center and Airbus — uses IBM's Watson artificial intelligence system to recognize and converse with crew members. One of the first tasks was to use CIMON as an intelligent flying camera during a complex medical experiment.

Also this year, **Russian space agency Roscosmos approved a plan to send two Final Experimental Demonstration Object Research robots to the ISS in 2019**. Russia has been developing the program since 2014. The robots were designed to replace humans in high-risk tasks in space.

There have been many developments in spacecraft on-orbit servicing. In January, Britain-based Effective Space signed its first contract with a "major regional satellite operator" to cover the launch of two of its Space Drone satellite life extension vehicles in 2020 for a multiyear agreement valued at more than $100 million. The DARPA-SSL Robotic Servicing of Geosynchronous Satellites mission progressed toward launch in spring 2021. The robotic payload, which the Naval Research Laboratory is constructing, held a preliminary design review in July. Many elements of the program, such as the robotic manipulators, are in flight production. The mission will include relocation, anomaly resolution, and upgrades to commercial and government client satellites.

Between June and August, **the Robotic Refueling Mission 3 completed space station electrical compatibility tests and validated methane operations, bringing the mission closer to December's expected launch**. Robotic Refueling Mission 3, a project of the Satellite Servicing Projects Division, or SSPD, at NASA's Goddard Space Flight Center in Maryland, will store and transfer cryogenic fluid in orbit, advancing satellite servicing and helping to enable long-duration space travel to the moon and Mars. For the Restore-L mission, which will robotically refuel a satellite not designed to be serviced, NASA personnel practiced autonomously tracking and grasping a client satellite's Marman ring by using a Hexapod robot to mimic a satellite's movement in space.

SSPD also designed an advanced tool drive system for NASA's Langley Research Center in Virginia and the Commercial Infrastructure for Robotic Assembly and Services project and issued two licenses for use of its Cooperative Service Valve, which helps make satellites more easily serviceable and one Space Act Agreement for SSPD enabling technologies. In August, SSPD's Robotics Tool Stowage project for providing storage of the Robotic External Leak Locator 2 outside of the ISS completed its critical design review.

In lunar robotics, the Google Lunar X Prize ended without a winner in January. However, some of the competing companies continued their work. For example, Moon Express is moving forward with its lunar-lander mission for 2019.

On Aug. 15, **China's State Administration of Science, Technology and Industry for National Defense announced it would launch its Chang'e-4 lunar lander and rover in December in the first attempt of a soft landing on the far side of the moon.**

Engineers at NASA's Jet Propulsion Laboratory in February and May operated a new drilling technique called feed extended drilling using the Curiosity rover on Mars. JPL engineers developed the technique using the force sensor feedback in the robotic arm to recenter the drill after a faulty motor prevented the drill from extending and retracting between finger-like stabilizers.

In January, the Mars Helicopter Team (JPL, AeroVironment, Langley and NASA's Ames Research Center) demonstrated their design in Mars-like conditions. As a result, in May the Mars Helicopter Technology Demonstrator was added to the Mars 2020 mission. ★

Blue Origin and SpaceX

▲ Blue Origin's New Shepard, left, and SpaceX's Falcon Heavy lead their companies' competition to launch paying passengers into space.

Falcon Heavy, New Shepard achieve important test flights

BY KOKI HO

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

This year has seen significant milestones in commercial space logistics as well as exploration in human space mission design.

The first launch and test flight of SpaceX's Falcon Heavy rocket was Feb. 6. The rocket carried a Tesla Roadster as a test payload and delivered it into space. The Falcon Heavy rocket is the most powerful operational rocket; its first stage is comprised of three Falcon 9-derived cores with 27 Merlin engines. It's capable of launching up to 64,000 kilograms of payload to low Earth orbit. The rocket is designed to be partially reusable. For the February test flight, the two side boosters were previously flown Falcon 9 first stages, whereas the central core was newly built. After the flight, the side boosters landed, although the center booster experienced engine failures and struck the ocean instead of landing on a floating landing pad (also referred to as a "droneship") in the Atlantic Ocean, as planned. SpaceX says it costs about $90 million for a Falcon Heavy flight, which is significantly cheaper than other heavy-lift launch vehicles. This achievement is a critical step toward commercial space exploration beyond low Earth orbit.

Blue Origin also performed two test flights of its New Shepard launch system, which is a reusable suborbital rocket designed to carry tourists as well as commercial and scientific payloads. The test flights were April 29 and July 18; both missions tested suborbital flight and landing of a reused booster. The July flight also demonstrated the operation of the abort system, for the safe return of future astronauts on the New Shepard during its flight.

On the human space mission design side, a team of space logistics subject matter experts prepared the "Logistics Is a Key Enabler of Sustainable Human Missions to Mars" white paper, which explores the question: What does the interplanetary logistics supply chain for a sustainable human presence on Mars look like?

The paper examines two particularly relevant present-day examples of robust exploration logistics supply chains, namely those supporting the International Space Station, or ISS, in low Earth orbit and the Amundsen-Scott South Pole Station on Antarctica. At these two locations, continuous human presence has been made possible by a combination of multi-modal logistics systems that facilitate multiple delivery pathways to the end user, generous stores of accessible contingency supplies and the exploitation of locally available resources. While the logistics of sustaining humans on future Mars missions will likely be far more challenging, the paper found implementable logistics strategies and persistent lessons learned from the South Pole Station and ISS programs that are directly applicable. The paper identifies research questions to be addressed, including higher fidelity characterization of logistics demands, assessing the impact of a logistics/aggregation node in a to-be-determined Martian orbit, and how this Martian logistics node might affect or be driven by the selection of the human landing site and exploration zone on Mars. ★

Contributors: *Robert Shishko, Sydney Do and Kandyce Goodliff*

U.S. Space Force proposal, commercial crew programs grab interest

BY CHRISTOPHER R. SIMPSON

The **Space Operations and Support Technical Committee** focuses on operations and relevant technology developments for crewed and uncrewed missions in Earth oribtal and planetary operations.

▶ **SpaceX's Crew Dragon** underwent testing in the In-Space Propulsion Facility at NASA's Plum Brook Station in Ohio.

Proposal of a U.S. Space Force, the nearing completion of demonstration commercial crew flights for SpaceX and Boeing, and an increased interest in servicing, tracking and autonomous satellite systems dominated space operations news.

According to the Satellite Industry Association's 2018 annual report, the commercial sector saw a 3 percent growth to $269 billion from 2016 to 2017. Worldwide government space budgets and commercial human spaceflight revenues totaled $79.3 billion in 2017.

American policy changes indicated a focus on space with the re-establishment of the National Space Council in February; the Space Policy Directive-2 in May; encouraging growth of America's commercial satellite industry; President Donald Trump's proposal in June to create a U.S. Space Force; and the Commercial Crew Program's first demonstration flight scheduled for 2019.

The Trump administration's push for a Space Force came after U.S. intelligence agencies warned of the growing capabilities of potential adversaries and the need to protect American assets in space, such as GPS, which provides the timing signal for the New York Stock Exchange and is part of ATMs and location services on smart devices. China added two new satellites to its GPS competitor, Compass Navigation Satellite System, and surpassed previous launch records with its 23rd of the year in August. Also that month, Russian space agency Roscosmos Director Dmitry Rogozin announced development was suspended of its Proton Medium — intended as a competitor with SpaceX's Falcon 9 — to focus on the Angara launch vehicle program. French Defense Minister Florence Parly, in a speech at CNES, the French space agency, in September said France suspects Russia tried to intercept secret communications when it flew a spy probe close to a European satellite 22,000 miles above the Earth last year. Parly mentioned the suspicions while announcing France's plans to spend $2.3 billion on space technology in 2019.

The U.S. Air Force announced in October that it had awarded launch service agreement contracts for Evolved Expendable Launch Vehicles to Blue Origin, Northrop Grumman Innovation Systems and United Launch Alliance. The LSA program aims to ensure the United States has access to at least two domestic commercial launch providers meeting national security requirements.


SpaceX

America might soon have the capability to fly astronauts on U.S. rockets again as SpaceX scheduled its first demonstration flight of the Dragon 2 for January 2019. SpaceX and Boeing are working toward crewed demonstration flights of the Dragon 2 and Starliner capsules in 2019. SpaceX was able to edge out Boeing as the first commercial spacecraft because of a propellant leak in Starliner's emergency abort system during testing in June. NASA announced in August the nine astronauts who will fly aboard the crewed test flights.

In January, an amateur astronomer rediscovered NASA's Imager for Magnetopause-to-Aurora Global Exploration, or IMAGE, satellite. IMAGE had been lost since 2005.

DARPA reported in August that its Robotic Servicing of Geosynchronous Satellites program will reach a system requirements review milestone in October.

In May, t**he first meeting of the Consortium for Execution of Rendezvous and Servicing Operations established a self-policing industry group for commercial on-orbit activities**. The University of Surrey RemoveDEBRIS mission in June tested methods to remove space junk. There are 2,000 active satellites in orbit.

Two companies launched satellites to provide broadband internet access. SpaceX launched two prototype satellites for its Starlink constellation in February. The company plans to have 4,500 satellites in the constellation. OneWeb's constellation will be at least 900 satellites and reportedly as many as 1,980. The company's first launch was scheduled for December. ★

Space resources community sets sights on the moon

BY MICHAEL HECHT, FORREST MEYEN AND LAURENT SIBILLE

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 space resources community this year took steps to respond to the new focus on lunar missions embraced internationally and in the U.S. by White House Space Policy Directive 1 issued in late 2017. Also, decisive investments were made by large launch services companies and small start-ups intent on creating a cislunar economy using space resources. In September, the Luxembourg Space Agency was founded in part to focus on the expansion of the country's space resources initiative in cooperation with a new European Space Agency program on space resources. NASA endorsed the importance of resource utilization in its exploration planning. "We are continuing to learn about our Moon and the value its resources can provide for human exploration," said Jason Crusan, NASA's director of advanced exploration systems, in a May press release.

Among this year's research, **Contour Crafting Corp. demonstrated 3D printing of large concrete structures** in collaboration with NASA's Kennedy Space Center in Florida, Marshall Space Flight Center in Alabama and the U.S. Army Corps of Engineers. Competitors in NASA's 3D-Printed Habitat Centennial Challenge continued aiming to build full-scale structures with lunar regolith simulant. Honeybee Robotics of California in February tested its 1-meter-class drill TRIDENT (short for Regolith and Ice Drill for Exploration of New Terrain) deployed from KREX-2 rover in the Atamaca Desert of Chile with partner NASA's Ames Research Center of California. The device could someday drill for water ice on the moon. The University of Texas at El Paso demonstrated combustion joining of ceramic tiles made from regolith simulant while Michigan Technological University completed feasibility tests of water-jet excavation of gypsum for water production on Mars.

Heriot-Watt University, Scotland and European Astronaut Centre, Germany

▶ **Glass mirrors were** made from simulated lunar regolith, possibly for use in a solar concentrator.

Developments in the in-situ resource utilization field also took place in the European Union, including work on the Lunar Volatiles Mobile Instrumentation rover. **In Belgium and Germany, scientists and engineers developed demonstration payloads for a commercial ISRU mission to be led by the European Space Agency**. Project RegoLight, in which researchers will attempt to 3D manufacture structures from lunar regolith, demonstrated sintering under vacuum with concentrated solar light. Meanwhile, Heriot-Watt University in Scotland used lunar regolith simulant to manufacture glass mirrors suitable for solar concentrators. Ispace, a Japanese company looking to exploit lunar water resources, finalized a $94.5 million Series A funding round in February and is planning a moon landing in 2021. In October, the company announced a partnership with Draper of Massachusetts to provide lunar landing guidance navigation and control software.

Mars isn't forgotten in NASA's ISRU plans either. **Engineers in October completed assembly of the Mars Oxygen ISRU Experiment, MOXIE, a 1:200 scale model of a device that might one day provide astronauts with oxygen propellant for their Mars ascent vehicle.** It's on track for delivery to the Mars 2020 rover by January 2019 for the first extraterrestrial ISRU demonstration in 2021. OxEon Energy LLC of Utah started development of a full-scale solid oxide electrolysis system, adding co-electrolysis of CO_2 and H_2O to produce O_2, CO, H_2, and ultimately CH_4 fuel. In May, NASA announced that OxEon Energy is among 10 companies and a university that will conduct studies and advance technologies to collect, process and use space-based resources for missions to the moon and Mars under the Next Space Technologies for Exploration Partnerships-2, NextSTEP-2, Broad Agency Announcement. Elsewhere, NASA is testing dust filters, carbon dioxide freezers and sorption pumps, solid oxide electrolyzers, Sabatier catalysts, excavation tools, and systems for extracting water from icy and hydrated soils on Mars.

A bellwether of the maturation of the field was the September debut at the Colorado School of Mines of the first graduate program focused on the exploration, extraction, and use of space resources. ★

"Lost" satellite reappears, water ice mapped at lunar poles

BY PATRICK R. CHAI

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

Amateur astronomer Scott Tilley in January recorded observation of a satellite in high Earth orbit, and with additional observations from NASA's Goddard Space Flight Center in Maryland and Johns Hopkins Applied Physics Lab, the satellite was confirmed to be NASA's Imager for Magnetopause-to-Aurora Global Exploration, or IMAGE, which had been assumed lost since 2005. Scientists and engineers at APL have communicated with the satellite since the discovery to understand how the spacecraft lost transmitting power in 2005 and how it began to transmit signals again.

In February, the Opportunity rover celebrated 5,000 sols on the Martian surface, more than 55 times its designed lifespan. The rover continued its mission on the red planet, having traversed more than 40 kilometers on Mars and making countless observations to help us understand the planet. A global dust storm enveloped Mars in June, forcing the rover to shut down and shelter in place.

The Curiosity rover celebrated 2,000 sols on the surface in March as it continues its primary mission of finding life on Mars. Engineers have been developing a new method for drilling since the rover's drill failed in 2016. The new method was tested, and the rover collected its first drilled sample in May.

NASA's Transiting Exoplanet Survey Satellite space telescope launched on a Falcon 9 rocket in April to search for exoplanets. Scientists expect the telescope to lead to a dramatic increase in the number of known exoplanets for future study by Earth-based telescopes and the James Webb Space Telescope. Before the primary mission began in late July, the spacecraft captured stunning images of the C/2018 N1 comet located 48 million kilometers from Earth in the southern constellation Piscis Austrinus.

In June, a near Earth asteroid, 2017 YE5, that astronomers at the Cadi Ayyad University's Morocco Oukaimeden Sky Survey Telescope discovered in late 2017 made its near Earth approach, and scientists used NASA's Goldstone Solar System Radar in California to make observations. Those observations, along with observations by researchers at Green Bank Observatory in West Virginia and the Arecibo Observatory in Puerto Rico, showed that the asteroid is two distinct objects that are near equal mass and form a binary system. The new observations indicated that the two objects revolve around each other once every 20 to 24 hours. The discovery of a binary object is not uncommon, but having two objects so close in size is rare.

Scientists at the European Space Agency announced in July that data collected by the Mars Express orbiter's Mars Advanced Radar for Subsurface and Ionosphere Sounding instrument showed liquid water buried under layers of ice at the Martian south pole. Years of development led to the subsurface-probing instruments used to confirm what has long been suspected of Mars. The data shows that the south polar region of the planet has many layers of ice and dust down to a depth of 1.5 km in the study area. In August, scientists from the University of Hawaii, Brown University and NASA's Ames Research Center in California used data collected by NASA's Moon Mineralogy Mapper instrument on India's Chandrayaan-1 spacecraft to show evidence of water ice at the lunar poles. Most of the water is found in the near-permanently shadowed craters at the poles. The discoveries on Mars and the moon could have momentous impact on the future of space science and human exploration beyond Earth orbit. ★

NASA

▼ **The distribution of** surface ice at the moon's south pole, left, and north pole, detected by NASA's Moon Mineralogy Mapper on India's Chandrayaan-1 spacecraft. Blue represents the ice locations, plotted over an image of the lunar surface, where the gray scale corresponds to surface temperature (darker representing colder areas and lighter shades indicating warmer zones). The ice is concentrated at the darkest and coldest locations, in the shadows of craters. This is the first time direct observation and definitive evidence of water ice on the moon.

NASA

Space elevator experiment sent to space station

BY SVEN G. BILÉN

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

▲ **An e-sail spacecraft** concept consisting of a rotating central hub spacecraft with three deployable multikilometer-length tethers.

A team lead by researchers from Shizuoka University in Japan in September launched an experiment to the International Space Station to demonstrate a critical space elevator capability. The experiment consists of two cubesats connected by a 10-meter cable along which a smaller "elevator car" moves using its own motor. Cameras record the movement.

Through NASA's Educational Launch of Nanosatellites program, the Miniature Tether Electrodynamics Experiment, or MiTEE, led by the University of Michigan was expected to be delivered to NASA in late 2018 for a launch late next year on the second flight of Virgin Orbit's LauncherOne rocket. MiTEE-1 uses a deployable, rigid, 1-meter boom to measure the electrodynamics of current collection to pico-/femto-scale satellites (satellite mass up to 200 grams) in the Earth's ionosphere. With respect to the cubesat electrical common, MiTEE-1 will apply a bias of about 200 volts to an end-body collector at the boom's end. The cubesat also will emit an electron beam to close the electrical circuit through the ionosphere, which will be characterized by a miniaturized Langmuir probe instrument.

Investigations at NASA's Marshall Space Flight Center in Alabama on electrostatic-sail, or e-sail, propulsion continued. In April, the Marshall team finalized its benchmark plasma chamber tests, which determined the amount of deep space thrust force created per meter of tether with a positive biased charge, how the force diminishes as the spacecraft travels away from the sun, and how the effective area of an e-sail changes with distance from the sun. It was determined that, at a distance of 1 astronomical unit from the sun, the thrust force generated per meter of tether with a 6-kilovolt positive bias is almost 1 millinewton per meter, dropping off linearly as the inverse of the distance to the 1.07 power (as opposed to the square of the distance as solar sails do). This concept will enable small scientific spacecraft to be placed out of the solar plane at a rate of 12 to 18 degrees per year or enable a mission to the edge of our solar system (the heliopause region) within eight to 10 years — the same distance Voyager 1 went in 34 years.

The Spanish Ministry of Economy, Industry and Competitiveness funded an 18-month project, which started in late 2017, at Universidad Carlos III de Madrid to explore the feasibility of the low-work-function tether concept. In such a system, **specialized coatings enable natural thermionic and photoelectric emission of electrons along a segment of tether, which can enable propellantless propulsion as it avoids the need of gas-fed hollow cathodes.** Work this year involved vacuum-chamber testing of conductive tapes coated with low-work function materials.

In February, the Phobos L1 Operational Tether Experiment, or PHLOTE, study team, led by NASA's Langley Research Center in Virginia and Star Technology and Research Inc., **developed a method of tether length control to manage the periodic motion of the Lagrange point due to the slight eccentricity of Phobos' orbit around Mars**. A PHLOTE architecture with this adjustable tether system can be used in synchronous rotation at asteroids to allow direct sampling of multiple equatorial sites without the need for propulsive landings. This method could also gently pull selected boulders off asteroids.

In March, the Bi-sat Observations of the Lunar Atmosphere above Swirls mission concept team, led by researchers at NASA's Goddard Space Flight Center in Maryland, wrapped up the development of its "sky crane" concept, which uses a tether to connect two small satellites so that the system can fly in a stable, frozen lunar orbit and get the lower satellite to fly within a few kilometers of the lunar surface. The team performed detailed simulations in the lunar potential field, confirming that the system's behavior will be stable and compatible with the mission requirements. ★

Small and large launch companies report successes

BY DALE ARNEY

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

After its record 18 Falcon 9 launches in 2017, SpaceX was on pace in November to surpass that number in 2018. SpaceX flew the final Block 4 version of the Falcon 9 in June, while the final Block 5 version optimized for reusability debuted in May. That same core was reused within three months. The first flight of SpaceX's Falcon Heavy in February launched a Tesla Roadster beyond Mars orbit. The Falcon Heavy was later certified to deliver national security payloads and was selected to launch an Air Force satellite in 2020.

United Launch Alliance, or ULA, added to its record with launches of the Atlas 5, Delta 4 M+ and Delta 4 Heavy. ULA also launched the final Delta 2 in September, ending its 29-year run after 155 launches. In August, Russia's Energomash signed a contract to sell RD-180 engines to ULA to power six additional Atlas 5 launches beyond 2020. In May, ULA selected Aerojet Rocketdyne's RL10 engine to power the second stage of its Vulcan Centaur heavy lift vehicle set to debut in 2020.

Blue Origin continued to test its New Shepard suborbital rocket, reusing the vehicle first flown in 2017. The BE-4 engine that will power the first stage of Blue Origin's future New Glenn orbital launch vehicle passed its technical tests, and the BE-3U upper stage engine underwent a hot-fire test in August.

Hardware for NASA's Space Launch System, or SLS, designed to send astronauts to the lunar vicinity in the 2020s, continued its progress this year. Aerojet Rocketdyne began fabricating long lead items for six new RS-25 engines for use after the fourth SLS flight. In August, the mobile launch tower made a test trip between the Vehicle Assembly Building and Launch Pad 39B at NASA's Kennedy Space Center.

SpaceX and Northrop Grumman Innovation Systems, formerly Orbital ATK, delivered cargo to the International Space Station with launches of the Falcon 9 and Antares 230, respectively. The launch in May marked the third flight of the Antares 230. SpaceX and Boeing continued development of their systems to deliver crew to ISS.

Interest and capital investment in small launch vehicles continued to increase this year, with 101 active small launcher companies identified during the Conference on Small Satellites in August. The final test flight of Rocket Lab's Electron launcher was completed in January ahead of its first commercial launch planned for late 2018. Virgin Galactic's SpaceShipTwo suborbital passenger vehicle underwent flight demonstrations this year, with a July flight setting records in both altitude (52 kilometers) and speed (Mach 2.47).

In August, **China launched its 23rd rocket of 2018, breaking its previous record of 22 launches set in 2016.** Private Chinese launch companies grew closer to operations, led by 2018 demonstrations of vehicles developed by companies OneSpace and i-Space. In June, the European Space Agency agreed to fund the development of the Ariane 6, set to launch in 2020 to replace the Ariane 5. Arianespace's Vega launch vehicle flew its 12th mission in August. In June, Russian space agency Roscosmos announced it would stop producing Proton rockets, which first launched in 1965, to focus efforts on its Angara.

In addition to the RL10 and RS-25, Aerojet Rocketdyne assembled the first AR-22 engine in June and tested key elements to a 13-kilowatt Hall thruster for NASA in August. The AR-22 supports DARPA's Phantom Express spaceplane, which has test flights expected in 2020. ★

NASA

▼ **A United Launch** Alliance Delta 2 sits on the launch pad Sept. 15 at Vandenberg Air Force Base in California before delivering the vehicle's final payload.

Hypersonic work escalates on multiple fronts

BY JAMES D. WALKER

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

This year witnessed a great increase in interest in the development of hypersonic weapons, defined as those that fly in the regime of Mach 5 to Mach 20 with the ability to maneuver in the atmosphere.

In March, President Putin of Russia announced in his state of the nation speech that Russia is developing maneuverable hypersonic missiles. On a large screen, he showed a conceptual animation of such a weapon in operation. China has a vigorous hypersonic research program as well.

In the U.S., meanwhile, former AIAA president Michael Griffin, the undersecretary of defense for research and engineering, elevated development of hypersonic weapons to a high priority. "We, today, do not have systems which can hold [adversaries] at risk in a corresponding manner, and we don't have defenses against those systems," he told Congress early in April. Griffin added that it is among the Pentagon's "highest priorities to erase that disadvantage."

▼ **In this time series,** starting from the top, a 5-centimeter-long blunt-body creates a shockwave and luminous glow after being launched to a speed of Mach 16 by a two-stage light gas gun at Southwest Research Institute in Texas. Collisions with air molecules disassociate these molecules into monatomic constituents and plasma with a temperature of 6,600 kelvin. The chamber replicated the atmosphere at an altitude of 70,000 feet.

Southwest Research Institute

Reflecting that priority, **the U.S. awarded large contracts for development of hypersonic weapons under a rapid prototyping authority**. In April, the Air Force awarded Lockheed Martin a $928 million contract to develop the boost-glide Hypersonic Conventional Strike Weapon. In August, Lockheed Martin received a second contract, this one for $480 million to develop the Air Launched Rapid Response Weapon.

The U.S. Army and Navy also are working on strike weapons that take advantage of the operation in the atmosphere to increase survivability and accuracy.

Ground test facilities geared up this year to address the aerothermal and structural research questions that need to be answered for the successful development of such systems. These include high-speed wind tunnels, arc-jet facilities, impact facilities, and a variety of systems for the thermal and mechanical testing of materials. Hypersonic flight conditions are nearly impossible to replicate for extended periods on the ground, but flight testing is also extremely expensive.

The challenge of operating in these regimes is the high heat flux rate into the vehicle. In hypersonic aerothermodynamics, the temperature is high enough around the vehicle that molecules break apart and reform. Accurate analysis of the flight in this regime includes understanding that chemistry. Speeds can be high enough that plasmas are formed around the vehicle that can interfere with communications, as experienced with returning space capsules and the space shuttle orbiters.

To defend against such weapons, **the Missile Defense Agency in September awarded 21 $1 million contracts to conduct concept studies into possible defenses**. Of these awards, five went to Lockheed Martin; four each went to Northrop Grumman and Raytheon; two each went to Boeing, Draper Labs and General Atomics; and BAE and L3 each received one.

Interest in hypersonic vehicle flight has waxed and waned over the years. This is essentially the fifth major wave into hypersonics. The first occurred at the beginning of the Space Age, with the X-15 and in understanding the re-entry environment for the Mercury, Gemini and Apollo capsules. The second wave occurred with the design of the space shuttle orbiters. Each orbiter executed a large S-turn in hypersonic flight to slow during re-entry, an example of the maneuverability of hypersonic vehicles. The third wave came with the National Aerospace Plane, or NASP, program, an unsuccessful effort to build an air-breathing single-stage-to-orbit vehicle. The fourth wave focused on supersonic combustion ramjet or scramjet technology, a kind of air-breathing engine, and finished with DARPA-funded experimental flights of the X-51 scramjet.

Hypersonic weapons come in two flavors, the boost-glide concept, in which a munition is boosted by a rocket and then glides back to Earth, similar to the space shuttle orbiters but not as big and fast. These weapons are within current technology and are the first being procured. The second approach would be air breathing weapons with more operational capability and extended range. Research into air-breathing propulsion continues with non-flight hardware. ★

Kevin Grantham

Recognizing NASA's 60th anniversary, World War I centennial

BY JULIAN TISHKOFF

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

▲ **This Royal Canadian** Air Force Lancaster Mk. X Bomber FM213 flew in for the Great British Fly-in at the Smithsonian Institution's Udvar-Hazy Center outside Washington, D.C., in Virginia.

The 60th anniversary of NASA was Oct. 1. NASA's Glenn Research Center recognized the milestone Sept. 29 with a tour of the center and a celebration at the Great Lakes Science Center in Cleveland. Also on Sept. 29, NASA's Goddard Space Flight Center in Greenbelt, Maryland, hosted a space demonstration and tours of its spacecraft integration and test facility.

Of the numerous NASA accomplishments, arguably the most recognized is the July 20, 1969, landing of Neil Armstrong and Buzz Aldrin on the moon. **Many commemorative 50th anniversary celebrations are planned or in progress**, including one that began in 2017 and has continued through 2018. The Smithsonian National Air and Space Museum prepared a traveling exhibit, Destination Moon: The Apollo 11 Mission, including the Columbia Apollo 11 command module and more than 20 unique mission artifacts. The exhibit was at Space Center Houston from Oct. 14, 2017, to March 18, 2018; the St. Louis Science Center from April 14 to Sept. 3; and the Sen. John Heinz History Center in Pittsburgh starting Sept. 29.

The Committee on Space Research, or COSPAR, celebrated its 60th anniversary, observed at the COSPAR 42nd Scientific Assembly on July 14-22 in Pasadena, California. COSPAR consists of eight scientific commissions and 11 technical panels. It reports to its council, which is comprised of representatives of 45 national and 13 international scientific unions. It also reports to the United Nations Office for Outer Space Affairs on such topics as planetary protection and space weather.

In its 60 years, COSPAR has led efforts of global community collaboration and scientific exchanges, inspiring and publicizing the earliest missions of Apollo to the moon, Viking to Mars, Giotto to Comet Halley, and Cassini to Saturn and Titan, as well as current explorations. It addresses all space sciences, including Earth and planetary studies, astronomy and human spaceflight and has been the catalyst for not only science, but also international cooperation. COSPAR conducts space science educational activities globally, as well as scientific exchange opportunities through its workshops and symposiums.

This year included numerous centennial commemorations of events that occurred during the final year of World War I. One notable event was the founding of the British Royal Air Force, or RAF. On April 15, the Smithsonian National Air and Space Museum's Steven F. Udvar-Hazy Center hosted the Great British Fly-In, which included RAF personnel, historical objects, lectures, and classic and modern British aircraft. The Canadian Warplane Heritage Museum's World War II Avro Lancaster bomber participated.

A World War I commemoration also was held at the 66th annual Experimental Aircraft Association fly-in convention July 23-29 in Oshkosh, Wisconsin, with a special emphasis July 27. Many of the aircraft displayed were associated with the 100th anniversary of the RAF. Among the aircraft was a newly restored De Havilland British-designed biplane with an American-built DH4 Liberty engine.

The University of Miami Libraries Special Collections is home to the Pan American World Airways Records, documenting aviation history from 1927 to 1991. Through grants from the National Historical Publications and Records Commission in 2018, this collection, including 100,000 pages of information, was digitized in an open resource that is full-text searchable. ★

Contributors: *Richard Hallion and Rachel Tillman*

Year of records includes Falcon Heavy launch, unmanned aircraft registrations

BY AMIR S. GOHARDANI

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

This year has seen many aerospace endeavors and notable records.

Boeing completed its 10,000th 737 jet in March. The first flight of a 737 was in 1967. The jet has been in service for more than 50 years.

Also in March, SpaceX launched its 50th Falcon 9 rocket. Falcon 9 took to the skies for the first time in June 2010; about eight years later, SpaceX launched a bigger version of the Falcon. In February, **millions of people worldwide watched the Falcon Heavy demonstration mission and launch**. The rocket carried and delivered into orbit a sports car as a dummy payload.

To date, United Launch Alliance delivered more than 120 satellites to orbit. This year, it launched satellites for a variety of missions. ULA is a joint venture between Boeing and Lockheed Martin.

There was also a continued interest in unmanned aerial systems, or UAS, this year. In January, U.S. Transportation Secretary Elaine Chao said **1 million recreational and commercial users had registered with the FAA's UAS registration program**. Perhaps the most significant near-term impact of UAS on society is that they can reduce emissions. A study published in Nature Communications in February led by researchers at Lawrence Livermore National Laboratory and Carnegie Mellon University found that using relatively small quad- or octo-copters (compared with larger military drones, for example) instead of diesel-burning delivery trucks could mean a reduction in both energy consumption and release of greenhouse gases that contribute to climate change.

This year also saw the first fatality on a U.S. airline in nine years, according to National Transportation Safety Board Chairman Robert Sumwalt. On April 17, a woman died on a Dallas-bound Southwest flight that made an emergency landing after engine failure. With the FAA forecasting that total U.S. airline passengers will increase from 840.8 million in 2017 to 1.28 billion by 2038, the need for even safer air travel shows the impact aerospace technology has on society.

▼ **U.S. astronaut Peggy Whitson** retired after setting several space records.

NASA

In February, NASA's New Horizons spacecraft broke a record by taking photographs from the farthest distance from Earth to date. The spacecraft was 6.12 billion kilometers from Earth. The photographs broke the record of the Voyager 1 spacecraft, which beamed back the famous "Pale Blue Dot" photograph in 1990 from 6.06 billion kilometers.

Also, this year, **Peggy Whitson, NASA's record-breaking astronaut, retired in June**, less than a year after returning from her last and longest spaceflight. Whitson has spent more time in space than any other American: 665 days over three space station missions. Whitson completed 10 spacewalks during her tenure — the most of any American — and was the first woman to command the International Space Station, holding the position twice. She was the oldest woman to fly in space. ★

NASA

FAA budget increase comes amid unmanned aircraft boom

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.

▲ **NASA researchers remotely** piloted this Ikhana aircraft through U.S. airspace without a chase plane, which is usually required to monitor surrounding airspace and provide warnings.

The five-year FAA Reauthorization Act of 2018 became law in October after six budget extensions had kept FAA's funding at 2012's level. The law was signed at a time that aerospace traffic management, or ATM, in the U.S. became increasingly challenging.

In January, the number of UAS, short for unmanned aerial systems, registered by the FAA reached 1 million, and the mission of drone operators and stakeholder vehicles continued to expand as high-altitude balloons, spacecraft and urban mobility aircraft became more common. These vehicles not only represent increased air traffic, but their operating characteristics present other problems to current ATM air-to-air separation, surveillance and management methodologies.

To address the pace of drone growth, NASA has accelerated the Unmanned Aircraft System Traffic Management program for drones in Class D airspace to define ways and means by which multiple flights can safely fly at altitudes below 400 feet beyond the line of sight of the operator. Working in concert with the FAA, industry and academia at designated test sites, NASA completed Technology Capability Level 3 demonstrations in May, which **focused on maintaining safe distances between responsive and nonresponsive drones over moderately populated areas.** In June, another milestone on the road to full drone integration into controlled airspace was achieved when NASA, in close collaboration with FAA, flew a large unmanned aircraft — the remotely piloted Ikhana Predator B — through national airspace without a chase plane.

In April, the FAA began the beta test and implementation of the Low Altitude Authorization and Notification Capability, which **aims to facilitate the sharing of airspace data between government and private industry so that approved drone operators can get near real-time access into controlled airspace near airports**. The actual authorization into controlled airspace via automation without any human intervention or oversight is groundbreaking. FAA also initiated the UAS Integration Pilot Program in May with 10 local, state and tribal organizations that in partnership with the private sector will explore further integration of drone operations. In Europe in March, the Single European Sky Air Traffic Management Research Joint Undertaking set out the road map for drone integration in Europe as a major contribution to coping with the burgeoning UAS activity there.

The Next Generation Air Transportation System Program, although criticized in some quarters for lack of progress, continued to move forward. The En Route Automation Modernization, Traffic Flow Management and Time Based Flow Management systems are in place while the Standard Terminal Automation Replacement System implementation, which was ongoing throughout 2018, is scheduled to be completed by 2019. The Automatic Dependent Surveillance-Broadcast, or ADS-B, and System Wide Information Management systems are available nationwide, and the Data Communications system will be in 62 airports by next year; 9,000 Performance Based Navigation system rotes are available, including at four metroplex locations.

Another dynamic increasingly affecting the U.S. aerospace traffic management system is the **expansion of FAA-licensed commercial space launch and re-entry activities**, which reached a high of 24 by September, exceeding the 22 of 2017.

In August, Aireon and the Irish Aviation Authority opened registration for air navigation service providers, aircraft operators, regulators, and search and rescue organizations for their free, global Aircraft Locating and Emergency Response Tracking service. Beginning next year, ALERT service will provide the last known position of an ADS-B-equipped aircraft that is in an apparent distress state or experiencing a loss in communication anywhere. When fully operational in 2019, this information would preclude situations such as the uncertainty over the loss of Malaysia Airlines Flight 370. ★

Contributor: *Charles Keegan*

Marching toward the 2030 vision of CFD

BY MUJEEB R. MALIK

In 2018, AIAA approved formulation of the **CFD Vision 2030 Integration Committee** to advocate for, inspire and enable 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.

The NASA sponsored CFD Vision 2030 Study presented a bold vision for physics-based computational capabilities when it was released in 2014. This road map guides research toward accomplishing this vision, and important work was carried out in 2018.

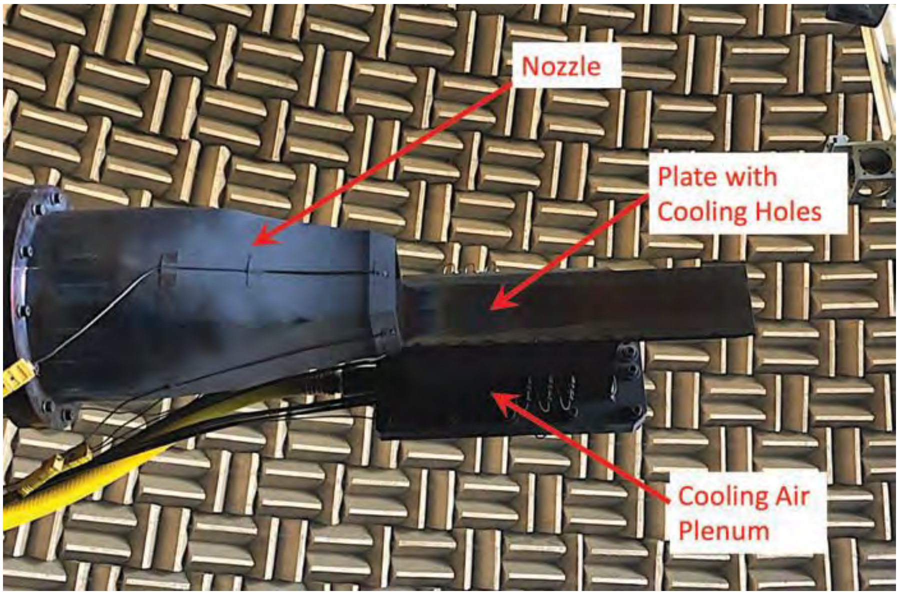
The vision study highlighted the role of leadership-class computing in achieving the simulation goals of the aerospace community. In a joint collaboration with NVIDIA Corp.; Old Dominion University; ParaTools Inc.; the U.S. Department of Defense High Performance Computing Modernization Program's Productivity Enhancement, Technology Transfer, and Training organization; and the Oak Ridge Leadership Computing Facility, **researchers at NASA's Langley Research Center in Virginia in May demonstrated impressive next-generation computational performance for the NASA Navier-Stokes solver FUN3D, an application for analyzing complex fluid flows.** The team explored a broad range of programming models appropriate for the many core architectures driving the current landscape of leadership-class high-performance computing facilities and used an approach based on the CUDA model to port and optimize the complete suite of FUN3D kernels. To demonstrate the efficiency of the implementation at scale, the team leveraged early access to Summit, the new IBM AC922 leadership-class system with NVIDIA Tesla V100 graphics processing units, or GPUs, installed at Oak Ridge National Laboratory in Tennessee. This system in June earned the rank of the world's most powerful supercomputer. Experiments were performed in April and May using as many as 1,024 hardware nodes, comprising a total of 6,144 Tesla V100 GPUs. The performance of the GPU approach was compared to that of a conventional hybrid MPI/OpenMP formulation running exclusively on the dual-socket IBM Power9 central processing units with 44 cores each. Tests showed a nominal 30x speed advantage for the GPU approach, or a total throughput equivalent to that of approximately 1 million central processing cores.

The study also emphasized the role of CFD validation experiments. Turbulence modeling research for high temperature flows has been rather limited, largely due to the difficulty of making detailed measurements in such flows. A series of tests, referred to as the Turbulent Heat Flux experiments, have been underway at NASA's Glenn Research Center in Ohio to collect data that could lead to advances in computational modeling of such flows. A square nozzle delivering a hot jet exhaust over a rectangular plate with 135 cooling holes was tested in May and June using particle image velocimetry and the Raman spectroscopy technique for velocity and temperature measurements, respectively. Extensive data was obtained for a range of nozzle exhaust temperatures and Mach numbers along with cooling hole blowing ratios. The configuration with a large number of cooling holes is representative of a high temperature nozzle exhaust or turbine blade.

In August, **NASA initiated negotiation for 12 research awards to various universities and industry to make advances in turbulence simulations, numerical algorithms, benchmark experiments, multidisciplinary analysis and optimization, and to establish requirements for aircraft certification by analysis.**

Also this year, researchers attending the Future CFD Technologies Workshop agreed to recommend better leveraging of advances made in fundamental disciplines within the aerospace CFD community, and fostering better collaboration between relevant stakeholder government agencies including NASA, the Energy and the Defense Departments. ★

Contributors: *Eric J. Nielsen, Nicholas J. Georgiadis and Dimitri J. Mavriplis*



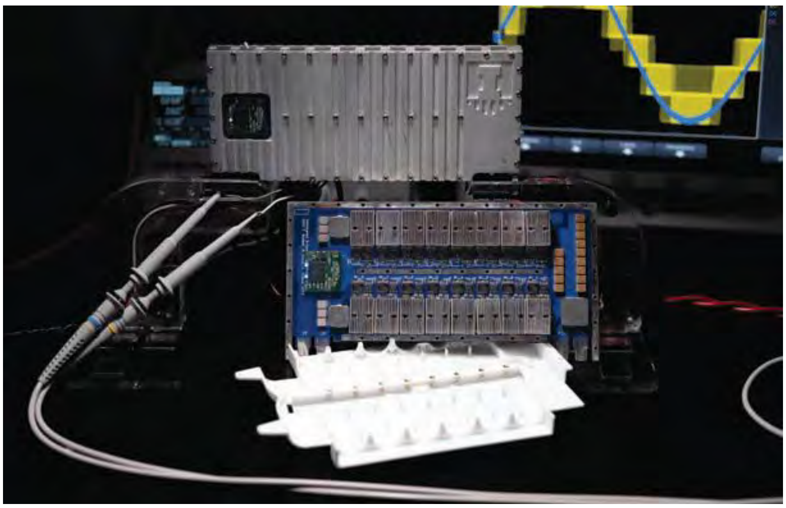
NASA

▼ **Experiments to** learn about cooling requirements for hot nozzle surfaces and turbine blades were run on this Turbulent Heat Flux test article at the Aeroacoustic Propulsion Laboratory at NASA's Glenn Research Center in Ohio. Hot air exits from the nozzle on to the plate (the test article), which has 135 tiny holes through which cold air is provided from the plenum. Air velocity and temperature measurements were made above the test plate.

Government and industry pour resources into electric power

BY JOHN NAIRUS, CHERYL BOWMAN, ELENA GARCIA AND MICHAEL IKEDA

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.



University of California, Berkeley

▲ **Hardware prototypes** of an inverter for high-density, low-inductance electric motors. The metal heatsink version, top, achieves an efficiency of 98.6 percent, and a power density above 17 kilowatts per kilogram. The version with micro-heatsinks and 3D printed plastic enclosure, bottom, is undergoing tests, and is expected to yield approximately a 50 percent power density improvement.

Aircraft power and thermal management continued to mimic the automotive industry's electrification trend. Early this year, the U.S. Air Force wrapped up its INtegrated Vehicle ENergy Technology, or INVENT program, which began in 2011. INVENT laid the foundation for future military power and thermal management development programs by advancing new technologies sized for insertion into today's aircraft while testing these technologies in power and thermal systems targeting next-generation aircraft. INVENT also improved the aerospace industry's understanding of how to develop and apply model-based engineering tools to design and test. The Air Force is using these tools to apply hybrid-electric propulsion and power technologies to unmanned aircraft to increase range and endurance.

New infrastructure that supports power and thermal management systems research and development rated from tens of kilowatts thru megawatt-class was moved into a systems integration facility in Dayton, Ohio. The Air Force repurposed the building in late 2017. It once housed a 5-foot wind tunnel with connections to Wilbur Wright.

At the Farnborough International Airshow in July, **Britain's Department for Business, Energy and Industrial Strategy announced a £255 million ($331 million) investment in greener flight technologies, including the Airbus E-Fan X hybrid-electric demonstrator**. The Airbus, Rolls-Royce and Siemens partnership is projecting component development in 2019 and flight testing in 2020. The E-Fan X will replace one of the four gas turbines on the British Aerospace 146 flying testbed with a 2 MW electric motor to explore high-power propulsion system challenges. Also at Farnborough, United Technology Corp. Aerospace Systems announced it was building a high-voltage electric systems lab in Rockford, Illinois, with plans to double the energy density of today's generators, motors and motor controllers from 5 kilowatts per kilogram to 10 kW/kg over the next few years.

The second annual Uber Elevate Summit took place in Los Angeles in May. Several companies announced plans for small air vehicles with passenger or package delivery capability. In October, **Safran Helicopter Engines was selected to provide engines for Zunum Aero's 12-seat ZA10 hybrid-electric aircraft with first commercial flights planned for the early 2020s**. The ZA10 is being designed for 700 miles of range, targeting regional airport operation. Initial flight tests are planned for 2019. The fatal crash in May of the eFussion aircraft, developed by Siemens and Magnus, was a reminder that experimental aircraft must be fully vetted before entering commercial operation.

The NASA Electric Aircraft Testbed, or NEAT, near Sandusky, Ohio, is focused on testing electric aircraft components and powertrains. **NEAT completed its first end-to-end powertrain testing in early 2018.** NASA is developing the testbed to support aircraft relevant powertrain testing under flight-like scenarios, which include elements of high voltage, distribution over realistic/large wingspan, electromagnetic interference and high power research hardware. The first flight altitude simulation testing of electrical components was scheduled to begin late in 2018 in a chamber designed to support up to 50,000-foot climb conditions within a 20-foot diameter, two-story chamber.

In October, NASA held a public review at the Ohio Airspace Institute of nine contracts that cover aircraft and component design for single-aisle-class hybrid or turboelectric vehicles. Component development highlights included General Electric Global Research Center's completion of a motor controller (inverter) that provides conversion for 1 MW at continuous power at greater than 99 percent efficiency and 17.5 kW/kg power density. The University of Illinois Urbana-Champaign, or UIUC, and Ohio State University also reported design completion and build progress for 1 MW motor designs. Testing for the UIUC motor was scheduled to start late in the year at the United Technology Corp. Aerospace Systems lab in Illinois. ★

Spitzer telescope endures, while Opportunity's fate is pending

BY LEENA SINGH AND SURENDRA P. SHARMA

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

▲ **The Mercury Planetary** Orbiter, part of the BepiColombo mission, during launch preparations at Europe's Spaceport in Kourou, French Guiana.
European Space Agency

This year, Spitzer Space Telescope, one of NASA's four Great Observatories, marked 15 years of operation since its August 2003 launch. Spitzer's contributions include exoplanet detections such as TRAPPIST-1's planetary system of seven Earth-sized planets; "direct light measurement" of exoplanets and their atmospheres triggering new methods in exoplanet science; and the development of an "exoplanet weather map" tracking surface temperature variations of certain classes of exoplanets. Spitzer's other contributions include updates to the universe's evolving star catalog; high-resolution spectral images of Saturn's rings relative to its moons; and the earliest detection of buckyballs in space. Spitzer was designed for a 2½-year primary mission, but the telescope has lasted well beyond its expected lifespan.

NASA's 15-year-old Mars exploration rover, Opportunity, has been silent since June after a dust storm encircled the planet, cutting off solar power to the rover and its ability to charge its batteries. Scientists are waiting to see if the rover will return to life from its low-power safe mode when the dust abates. Opportunity and its mate, Spirit, arrived on Mars in 2004 with a planned mission life of 90 Martian days. Opportunity has traveled more than 25 miles on the Martian surface. In February, it descended into Perseverance Valley, sending home pictures of rock stripes that suggest the one-time presence of water or ice. The InSight mission to Mars was launched in May. The probe was expected to land in late November and then go on to measure surface heat flow and seismic activity from Mars' deep interior to understand how the rocky planet formed.

In June, Japan Aerospace Exploration Agency's Hayabusa2 spacecraft rendezvoused with the asteroid Ryugu. Its mission was to collect a sample of asteroid material for return to Earth and to deploy four small rovers. In August, NASA's asteroid-sample-return spacecraft, OSIRIS-REx, arrived within sighting distance — 2.2 million kilometers — of its target asteroid, Bennu, and commenced approach operations. Part of the New Frontiers program, OSIRIS-REx is NASA's first mission to a near-Earth asteroid. The spacecraft will perform rendezvous maneuvers, including multiplanar flybys of Bennu, to build a mass and microgravity model and survey the asteroid's surface. Eventually, OSIRIS-REx will descend to collect soil samples and return to Earth. For its survey operations, OSIRIS-REx is richly equipped with a multicamera suite, multispectrometer suite and laser altimeters. The spacecraft, launched in September 2016, was scheduled to arrive at Bennu in December.

NASA's Parker Solar Probe launched in August to investigate the sun's outer corona and solar wind. The spacecraft, which will approach within 4 million miles of the surface, will be protected by a carbon-carbon heat shield from external temperatures approaching 1,377 degrees Celsius.

Meanwhile, the Mercury mission, Bepi-Colombo, launched in October as a joint project of the European Space Agency and Japan Aerospace Exploration Agency. The spacecraft triad, a transfer module carrying two science orbiters, will travel together using a combination of solar and electric propulsion, or SEP, aided by nine gravity-assist planetary flybys. Once in their target orbits, the two science spacecraft will make complementary measurements of the planet and its environment, from its interior to its interaction with solar wind. The results will provide insight into how a solar system's innermost planets form and evolve close to the parent star.

NASA made important first steps this year to realize its gateway in lunar orbit with formal calls to commercial partners for proposals to build the gateway's power and propulsion element — a 50-kilowatt SEP system — for first flight demonstration in 2022. NASA's Exploration Campaign plans to establish the gateway to serve as a stepping off point to define a sustainable and viable architecture for cislunar operations, lunar access and missions to Mars and beyond. Together with the Space Launch System and Orion, gateway is central to advancing and sustaining human space exploration goals. ★

Dozens of urban air mobility projects underway

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 second century of aviation offers the building blocks for a second air transportation revolution. Many companies this year focused on enabling urban air mobility, or UAM, which can be defined broadly as small, electric-powered vertical takeoff and landing, or eVTOL, aircraft designed to fly small groups of travelers (typically nine or fewer) or cargo across metropolitan regions faster than ground vehicles. This year, the Vertical Flight Society's eVTOL.news directory listed 100 eVTOL aircraft projects in various stages of development. While the most visible activities are vehicle projects, the realization of UAM requires breakthroughs in airspace, operations, regulation and community integration.

Uber hosted its second Elevate Summit in Los Angeles in May. With 750 participants, the summit focused on building a broader foundation of technical, financial and community support around urban aviation and emphasized the opportunities for businesses and entrepreneurs in vehicle development and manufacturing; flight and fleet operations; network operations; and skyport design, development and operations.

Also at the summit, Jaiwon Shin, associate administrator for NASA's Aeronautics Research Mission Directorate, announced a NASA-sponsored UAM Grand Challenge. NASA said the challenge will be a sequence of activities involving aircraft developers, air traffic service providers, regulators, communities and other members of the broader UAM ecosystem who will progressively build up and demonstrate the safety and effectiveness of a UAM transportation system.

The Kitty Hawk Corp., a startup funded by Google co-founder Larry Page, announced two eVTOL projects that are conducting flight operations. First is Cora, a remotely piloted, two-passenger air taxi prototype unveiled in March. Cora was undergoing flight testing and development in both California and New Zealand. The second Kitty Hawk aircraft is a refined version of the "Kitty Hawk Flyer" announced in 2017. The refined Flyer is an amphibious, 10-rotor multicopter configuration that avoids many regulatory issues by operating as an ultralight aircraft in the U.S. As an ultralight, it can be operated without an FAA pilot's license while a fly-by-wire control system provides simplified controls and enforces various safety limits such as a 10-foot maximum altitude and geofencing. In addition to the Kitty Hawk projects, a third Page-funded project, known as the Blackfly — developed by the Opener company — was announced in July on CBS after having performed 1,400 flights, covering 12,000 miles. The Blackfly also operates as an ultralight and has powered-lift and wing-borne flight modes.

In July, the U.S. House of Representatives science committee held a hearing called "Urban Air Mobility — Are Flying Cars Ready for Take-Off?" Testimony on the potential and challenges of UAM was provided by NASA's Shin; John-Paul Clarke, Georgia Tech's College of Engineering dean's professor; Eric Allison, head of aviation programs at Uber; Michael Thacker, executive vice president of technology and innovation at Bell; and Anna Mracek Dietrich, co-founder of Terrafugia. Most panelists predicted initial commercial operations within a 10-year horizon but acknowledged that large investment and development are required for operations on a significant scale.

▼ **Kitty Hawk's Cora** aircraft in an artist's rendering.

Kitty Hawk Corp.

In September, the UAM subproject of NASA's Air Traffic Management Exploration project, or ATM-X, completed data collection for an initial, human-in-the-loop simulation experiment evaluating UAM airspace operations. The experiment evaluated initial routes and procedures for flying UAM traffic in Class B and D airspaces in the Dallas-Fort Worth terminal airspace as well as assessing the impact of UAM traffic on air traffic controller workload. ★

Unmanned aircraft systems make research and business advances

BY RICHARD S. STANSBURY

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

U.S. Navy

▲ **A UH-1H Huey test** aircraft flies autonomously under the control of the Autonomous Aerial Cargo Utility System in a demonstration for the U.S. Marine Corps.

Unmanned aircraft systems integration continued to move forward this year. In July, the FAA reported that 100,000 remote pilot certificates had been issued since Title 14 Code of Federal Regulations Part 107 for small unmanned aircraft systems, or UAS, was issued in August 2016. To streamline and expedite the authorization process for small UAS operations within controlled airspace near airports, the FAA expanded the Low Altitude Authorization and Notification Capability, or LAANC, with a national test. The LAANC system's beta test began in April, covering the south central region of the United States and expanding to other regions throughout 2018 with a target of 500 airports and 300 air traffic facilities.

In May, the FAA announced the winners of the UAS Integration Pilot Program, which began in December 2017. The winners represented local, state and tribal authorities that will partner with industry to accelerate UAS integration through operational concepts, including beyond line-of-sight operations, operations over people and nighttime operations.

Research milestones have further enabled future UAS integration. NASA's UAS Traffic Management System, or UTM, supported by industry, government and academia partners, completed its Technical Capability Level 3 tests in May at the Nevada Institute for Autonomous Systems at the Reno-Stead Airport-based UAS test site. Under the third-level tests, the UTM system's capabilities are broadened to enable aircraft separation and spacing for both cooperative and noncooperative UAS over moderately populated areas. In June, General Atomics Aeronautical Systems Inc. and NASA flew the Ikhana UAS, a modified MQ-9 Predator, from Armstrong Flight Research Center in California for a 2½-hour flight without a chase aircraft. **It was the first demonstration of a large UAS without a chase aircraft** and provided an opportunity for verification and validation of RTCA standards for UAS detect-and-avoid.

The UAS industry saw numerous major business and operational milestones. In April, the **General Atomics Aeronautical Systems' Predator family of UAS achieved 5 million flight hours**. In May, Aurora Flight Sciences demonstrated its Autonomous Aerial Cargo Utility System integrated with a UH-1H Huey helicopter by delivering cargo to U.S. Marines at Marine Corps Air Ground Combat Center in Twentynine Palms, California. Also in May, the U.S. Interior Department contracted with four UAS companies to expand its UAS fleet for wildfire monitoring. In June, the U.S. Coast Guard awarded a contract to Boeing to operate the ScanEagle small UAS aboard its national security cutter fleet. In August, Boeing received an $805 million contract to develop the MQ-25 UAS, which will be the Navy's first carrier-based UAS, supporting aerial refueling.

UAS participated in several humanitarian missions this year. The German Aerospace Center in collaboration with the Wings for Aid and U.N. Food Program conducted UAS operations in the Dominican Republic for humanitarian supply delivery in May and June. In August, Direct Relief and other industry partners evaluated UAS for delivery of critical medical supplies in Puerto Rico with the goal of enhancing post-disaster medical aid in remote or inaccessible areas.

UAS were also flown for atmospheric and planetary sensing. In June, researchers and students from the University of Colorado-Boulder flew a UAS into a supercell thunderstorm to collect atmospheric measurements near Norris, South Dakota. In July, 100 participants with 50 small UAS platforms conducted the Lower Atmospheric Process Studies at Elevation — a Remotely-piloted Aircraft Team Experiment at the International Society for Atmospheric Research Using Remotely Piloted Aircraft meeting in Boulder, Colorado. The experiment involved **1,278 flights over eight days with FAA authorization for altitudes up to 3,000 feet to collect boundary layer measurements of mountain-driven weather**. In addition to earth science missions, new projects involving UAS planetary exploration began this year, including Black Swift Technologies receiving a contract from NASA to develop a UAS for planetary atmospheric observations of Venus. ★

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AIAA Bulletin

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

Calendar

FEATURED EVENT

7–11 JANUARY 2019

San Diego, CA

Innovation in aerospace starts at the AIAA SciTech Forum! The forum covers the science, technologies, and policies that are shaping the future of aerospace. The largest event for aerospace research, development, and technology in the world brings together 11 individual technical disciplines and includes over 4,000 attendees from nearly 1,000 corporate, academic, and government institutions in 42 countries.

scitech.aiaa.org/register

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2018			
6 Dec	DirectTech Webinar—Complexity in Aerospace Systems—Expecting the Unexpected	Virtual (aiaa.org/onlinelearning)	
2019			
5–6 Jan	2nd AIAA Geometry and Mesh Generation Workshop	San Diego, CA	
5–6 Jan	Aircraft and Rotorcraft System Identification Engineering Methods for Manned and UAV Applications with Hands-on Training Using CIFER® Course	San Diego, CA	
5–6 Jan	Design of Aircraft Structures Course	San Diego, CA	
5–6 Jan	Design of Electrified Propulsion Aircraft Course	San Diego, CA	
5–6 Jan	Diagnostics for Plasmas and Gases Course	San Diego, CA	
5–6 Jan	Fundamentals of Space Systems Course	San Diego, CA	
5–6 Jan	Guidance, Control, and Astrodynamics of Space Vehicles Course	San Diego, CA	
5–6 Jan	Integrating Program Management and Systems Engineering Course	San Diego, CA	
6 Jan	A Unified Approach for Computational Aeroelasticity Course	San Diego, CA	
6 Jan	Additive Manufacturing: Structural and Material Optimization Course	San Diego, CA	

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

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
6 Jan	Hypersonics: Test and Evaluation Course	San Diego, CA	
7 Jan	AIAA Associate Fellows Recognition Ceremony and Dinner	San Diego, CA	
7–11 Jan	AIAA SciTech Forum (AIAA Science and Technology Forum and Exposition)	San Diego, CA	11 Jun 18
13–17 Jan*	29th AAS/AIAA Space Flight Mechanics Meeting	Maui, HI	14 Sep 18
28–31 Jan*	65th Reliability and Maintainability Symposium (RAMS 2019)	Orlando, FL (www.rams.org)	
2–9 Mar*	2019 IEEE Aerospace Conference	Big Sky, MT (www.aeroconf.org)	
20 Mar	AIAA Congressional Visits Day (CVD)	Washington, DC (aiaa.org/CVD)	
25–27 Mar*	54th 3AF International Conference on Applied Aerodynamics	Paris, France (http://3af-aerodynamics2019.com)	
3–5 Apr*	5th CEAS Conference on Guidance, Navigation & Control (2019 EuroGNC)	Milan, Italy (www.eurognc19.polimi.it)	
29 Apr–3 May	2019 IAA Planetary Defense Conference	Washington, DC (pdc.iaaweb.org)	
7–9 May	AIAA DEFENSE Forum (AIAA Defense and Security Forum)	Laurel, MD	20 Nov 18
14 May	AIAA Fellows Dinner	Crystal City, VA	
15 May	AIAA Aerospace Spotlight Awards Gala	Washington, DC	
20–23 May*	25th AIAA/CEAS Aeroacoustics Conference (Aeroacoustics 2019)	Delft, The Netherlands	15 Oct 18
27–29 May*	26th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (elektropribor.spb.ru/icins2019/en)	
10–13 Jun*	18th International Forum on Aeroelasticity and Structural Dynamics	Savannah, GA (http://ifasd2019.utcdayton.com)	
12–14 Jun*	The Sixth International Conference on Tethers in Space (TiS2019)	Madrid Spain (http://eventos.uc3m.es/go/TiS2019)	
17–21 Jun	AIAA AVIATION Forum (AIAA Aviation and Aeronautics Forum and Exposition)	Dallas, TX	7 Nov 18
11–15 Aug*	2019 AAS/AIAA Astrodynamics Specialist Conference	Portland, ME (space-flight.org)	5 Apr 19
19–22 Aug	AIAA Propulsion and Energy Forum (AIAA Propulsion and Energy Forum and Exposition)	Indianapolis, IN	31 Jan 19
21–25 Oct*	70th International Astronautical Congress	Washington, DC	28 Feb 19

● AIAA Continuing Education offerings

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

News

Greater Huntsville Section at AirVenture 2018

By Ken Philippart

Section members at the iconic Brown Arch. Credit Susan Mallett.

Members of the AIAA Greater Huntsville Section attended the world's largest aviation gathering, the Experimental Aircraft Association (EAA) AirVenture in Oshkosh, WI, from 22–29 July. Section members met during the week to socialize while enjoying all that AirVenture offered.

Over 600,000 people attended AirVenture 2018 to enjoy viewing all things aviation on Whitman Field, including over 10,000 aircraft ranging from operational military aircraft, home builts, vintage warbirds, antique general aviation (GA) aircraft, ultralights, unmanned aerial vehicles and powered parachutes. Daily airshows included military flybys, aerobatics, vintage warbird formations, World War II reenactments, wing walking, drone shows, parachuting teams and commemoration of events such as the 80th anniversary of the legendary T-6 trainer, the Year of the Tanker, and the 100th anniversary of the Royal Air Force.

Historical talks were held by aviation legends like Dick Rutan, triple Ace Col Bud Anderson, and aerobatics legend Patty Wagstaff. Section members also tried their hands at homebuilding skills during hands-on build sessions by pulling rivets and practicing welding among other hands-on sessions such as TIG welding, sheet metal forming, and fabric covering of aircraft.

Section members met up at the historic Roxy Supper Club along with a diverse group of aviation enthusiasts including an EAA chapter president, GA pilots and certified flight instructors, and Gary Powers, son of U-2 pilot Francis Gary Powers who was shot down over the Soviet Union during the Cold War. The stories and passion for flight from the group of aviation experts made for an enjoyable evening befitting AirVenture's moniker as an "aviation family reunion." Plans are being made to return in 2019. See you in Oshkosh!

2018 AIAA Freitag Award Presented

The 12th Joseph Freitag, Sr. Award was presented to **Max Schrievers** on 12 September in Stuttgart, Germany. He received his diploma in Industrial Mechanics from the Daimler Benz Instruction and Training School, Stuttgart, Germany, in January 2018. Schrievers received an outstanding academic record while attending Daimler and was selected for the award by the school's master instructors. Schrievers stood out for willingness to tutor other students attending the school. Schrievers, 22, is currently enrolled in the Esslingen College School of Engineering, where he is pursuing a Bachelor of Mechanical Engineering.

AIAA Announces Candidates for 2019 Election

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

Elections will open in February 2019. Executive Nominating Committee Chair James Maser, Council Nominating Committee Chair Jane Hansen, and AIAA Governance Secretary Christopher Horton confirmed the names of the candidates who will appear on the 2019 ballot.

The nominees are:

President-Elect
- Basil Hassan, Sandia National Laboratories
- George Nield, Commercial Space Technologies, LLC
- Wanda Sigur, Lockheed Martin Corporation (Retired)

Director - Region IV
- Terry Buress, Lockheed Martin Aeronautics Company
- Sarah Shull, NASA Johnson Space Center

Director - Region V
- Kristen Gerzina, Northrop Grumman Corporation
- Orval "Rusty" Powell, Millennium Engineering and Integration Company

Director - Aerospace Outreach Group
- Tucker Hamilton, United States Air Force
- G. Alan Lowrey, Jacobs Space Exploration Group

Director - Integration Group
- Peter Hartwich, Boeing Engineering, Test & Technology

Director - Information Systems Group
- Allan (Terry) Morris, NASA Langley Research Center

Director - Propulsion and Energy Group
- Joaquin Castro, Aerojet Rocketdyne

On 1 November, at the Women in Aerospace Awards Dinner, AIAA Executive Director Emeritus Sandy Magnus was honored with the Aerospace Awareness Award, "in recognition of her work raising awareness of STEM and aerospace to diverse, global audiences, and engaging students in aerospace to grow the next generation workforce." She is pictured with Mike Griffin, former AIAA president, who presented her with the award.

(Credit: Larry Canner Photography)

CALL FOR NOMINATIONS

AIAA Foundation Award for Excellence

The AIAA Foundation Award for Excellence acknowledges outstanding achievements by individuals or groups in the aerospace community. Eligible nominees will offer a unique achievement or extraordinary lifetime contributions inspiring the global aerospace community.

Nomination Deadline:
11 January 2019

If you have any questions or if you need assistance please contact Felicia Livingston, Foundation Program Coordinator, AIAA Foundation, at 703.264.7502 or felicial@aiaa.org.

MAKING AN IMPACT

Daedalus 88 Scholarship Winner Is Inspired to Make Science Come to Life

By Michele McDonald

A can-do attitude and love for rocketry unite AIAA President John Langford and Sam Zorek, an engineering senior at Rice University and the first recipient of the $10,000 Daedalus 88 scholarship. Langford created the AIAA Foundation Daedalus 88 Undergraduate Scholarship to promote and support student entrepreneurship in aerospace.

"Education is not just classroom learning," Langford said. "It is experience-based, project-based learning. I think that's how I learn best, and it's how many people learn best."

The scholarship commemorates the 30th anniversary of the Daedalus Project, a pivotal project for Langford and 39 other MIT students. The team set a new distance record for human-powered flight by flying 72 miles between the Greek islands of Crete and Santorini. The record remains undefeated.

After the flight, Langford founded Aurora Flight Sciences Corporation, a pioneer in unmanned aircraft and autonomous flight, at a time when the industry saw few aerospace startups. For nearly 30 years, Aurora has designed, built and flown over 30 aircraft. In November 2017, Aurora was acquired by Boeing and continues to be a leader in autonomous technology today.

This fall, Langford invited Zorek for a behind-the-scenes tour of Aurora. He also gave Zorek and guests a rare, first-hand account of the influential Daedalus project and how its entrepreneurial know-how continues at Aurora.

Zorek's eighth grade science teacher, Christopher Goff, helped create an interest in STEM. "As a student, I was more inclined to build a slingshot out of rubber bands and a binder than pay attention to what was on the board. In Mr. Goff's science class, he made the equations come to life."

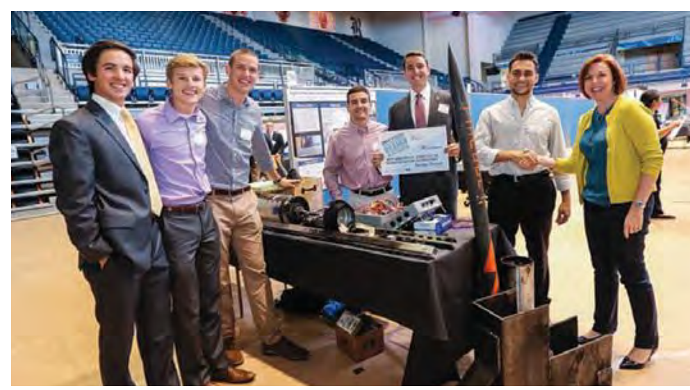
It was the fun egg-drop capsule test that drew Zorek to aerospace engineering. As part of his class project, he had studied how NASA landed the Mars rovers, Spirit and Opportunity and using Styrofoam, bubble wrap, and a lot of hot glue, his capsule kept the egg safe after dropping from three flights of stairs. Zorek was hooked. "I became more interested in school because I could see it wasn't a means to the end but a means to do better for the world."

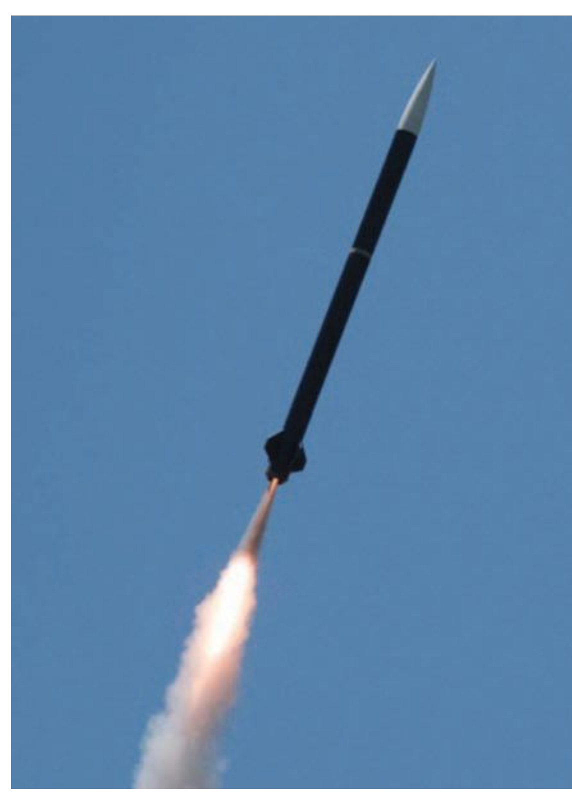
The tour at Aurora had a similar impact. "As I toured Aurora with Dr. Langford, I saw how his innovative aircraft designs today originated from the Daedalus student project 30 years ago," said Zorek, who's also president of Rice Eclipse, the university's student rocket team. "It inspires me to dream big and consider how I can apply the leadership lessons I learned from Dr. Langford to further grow Rice Eclipse."

Applications for 2019 AIAA Foundation scholarships are being accepted until 31 January 2019. For information on establishing a scholarship or to make a donation, please visit aiaafoundation.org.

Rockets have been part of the hands-on learning experience for both Langford and Zorek, who's working on dual degrees in mechanical engineering and policy studies, and also is president of Rice University's rocket team, Rice Eclipse. Langford received his first rocket as a fifth grader and is an active participant in Team America Rocketry Challenge.


RICE ECLIPSE





Ilcewicz Wins AIAA Walter J. and Angeline H. Crichlow Trust Prize

Dr. Larry B. Ilcewicz, chief scientific and technical advisor for Advanced Composite Materials at the FAA, has been selected to receive the 2019 Walter J. and Angeline H. Crichlow Trust Prize, which will be presented during an awards luncheon held on 10 January 2019 at the AIAA SciTech Forum in San Diego, CA. Ilcewicz's work has been instrumental as the aviation industry transitions from all-aluminum aircraft to composite materials. He also has made significant research contributions to the Boeing 777. He is being honored "For exemplary technical leadership in establishing a safety and regulatory framework enabling large-scale structural application of composites in commercial and general aviation aircraft, rotorcraft and engines." The award includes a medal, a certificate of citation and a $100,000 honorarium.

In 1998 Ilcewicz joined the FAA as chief scientific and technical advisor for advanced composite materials following many years in prominent positions developing composite materials and structures technology at Boeing Commercial Airplanes (BCA). In his FAA position, he has worked to advance composite materials and structures technology and develop coordinated strategies to address certification issues and service issues for composites. This work culminated in the FAA Aviation Safety Office (AVS) Strategic Composite Plan, an international plan for composite safety and certification initiatives.

Ilcewicz also serves as co-chair of the Composite Material Handbook 17 (CMH-17) Working Group, which develops and publishes extensive documentation of standard methods, material databases and engineering guidelines to meet the needs of industry and the general public. As part of this effort, Ilcewicz created a forum with Boeing, Airbus, regulators and academia.

Ilcewicz was awarded a dual degree Ph.D. in Mechanical Engineering and Materials Science from Oregon State University in 1984. During his Ph.D., he performed contract work on advanced composite resin matrices with toughened interlayers for the Boeing Company ACDP. He also received an M.S. degree in Wood Science from Oregon State University in 1979, and a B.S. degree in Wood Science and Technology from Michigan Technological University in 1977. He is author or co-author of 79 technical publications.

More information about Dr. Ilcewicz and the Crichlow Trust Prize can be found at aiaa.org/Larry-B-Ilcewicz-to-Receive-2019-Crichlow-Trust-Prize.

Nominate Your Peers and Colleagues!

NOW ACCEPTING AWARDS AND LECTURESHIPS

PREMIER AWARD
- Daniel Guggenheim Medal

TECHNICAL EXCELLENCE AWARDS
- Aerospace Power Systems Award
- Air Breathing Propulsion Award
- Dr. John C. Ruth Digital Avionics Award
- Energy Systems Award
- Hypersonic Systems and Technologies Award
- Propellants & Combustion Award
- Space Automation and Robotics Award
- Space Operations & Support Award
- Space Processing Award
- Space Systems Award
- von Braun Award for Excellence in Space Program Management
- Wyld Propulsion Award

LECTURESHIPS
- Dryden Lecture in Research
- Durand Lecture for Public Service

Please submit the four-page nomination form and endorsement letters to **awards@aiaa.org** by **1 February 2019**

For more information about the AIAA Honors and Awards Program and a complete listing of all the AIAA awards, please visit **aiaa.org/HonorsAndAwards**.

AIAA
SHAPING THE FUTURE OF AEROSPACE

STEM to STEAM — Society and Aerospace Technology Integration and Outreach Committee

By Dr. Amir S. Gohardani, SAT IOC, Chair

The Society and Aerospace Technology Integration and Outreach Committee (SAT IOC) takes immense interest in topics linking society to aerospace technology. In an effort to bridge Science, Technology, Engineering, and Mathematics (STEM) with the Arts into Science, Technology, Engineering, Arts, and Mathematics (STEAM), SAT IOC has arranged a panel session at the upcoming 2019 AIAA SciTech Forum in San Diego, CA. The panel will take place on Thursday, 10 January at 1600 hrs.

For centuries, visualization has been an essential engineering discipline. From Roman aqueducts and the sketchbooks of Leonardo da Vinci to the Spitfire and Concorde, good engineering has remained as much a matter of intuition and nonverbal thinking as of equations and computation. History has shown that engineers are best taught how to understand engineering drawings by making them and that they can still enhance their understanding of the nature of materials through experience. Visualization can indeed provide engineers with a feel for a problem. In aerospace engineering, a wide range of graphical representations of knowledge continues to serve as visual tools for innovation, problem solving, documentation, and communication. Fine arts have continuously brought unique opportunities to energize, promote, entertain, and inspire. STEAM efforts benefit from the ability to visualize and convey complex ideas through visualization.

The goal of the panel session, entitled From Functional to Inspirational Aerospace Art: STEM to STEAM, is to demonstrate how aerospace art is used to visualize advanced concepts, communicate technological advances, build cohesive teams, document historic events, and how it can impact the STEAM classroom. Conference attendees will learn about the panel's continuing quest to use visual art with students. It combines the perspectives of 5 AIAA members: the moderator (a fine arts curator, art lecturer and past TC Chair); three award-winning aerospace artists who are career engineers and researchers; and a STEAM education director with comprehensive aerospace experience.

Moderator: Cam Martin
Artist/Research Pilot: Mark Pestana
Artist/Engineer: Michelle Rouch
Artist/Engineer: Aldo Spadoni
Aerospace STEAM Education Director: Kathleen Fredette

All AIAA SciTech Forum attendees are cordially welcome to attend this session hosted by SAT IOC.

Obituary

Associate Fellow Nash Died in July

Don E. Nash, who had been an AIAA member since 1964, died on 28 July. He was 83 years old.

Nash began his career at McDonnell Aircraft (McAir) F-101 and F-4 Design groups followed by U.S. Army service. After his Army discharge and earning a B.S. in Aerospace Engineering in 1964 from the University of Oklahoma, he returned to the McAir Flight Test Division. He was assigned as the Flight Test Engineer for the 1st F-4J Carrier Suitability test and the 1st F-4D Radar Homing & Warning System. In 1969, he was assigned to the F-15 Proposal Team where he wrote a major section for Research and Development flight testing to include initial envelope expansion, stability and control, flying qualities, spin and structural dynamics testing.

When McAir won the F-15 contract Nash became Test Director for the 1st F-15 throughout its entire DT&E test program at St. Louis (1970–1972) and then Edwards AFB (1972–1975). In May 1972, Don received an M.S. in Engineering Management from the Missouri Science and Engineering University at Rolla, MO. In 1977 Nash relocated to Albuquerque, NM, where he joined BDM as a Staff Engineer and rose to vice president of the BDM Support contract for the Airborne Laser Lab (1977–1983) and the High Energy Laser Scientific Test Facility at the White Sands Missile Range. He was then assigned as vice president of Nuclear Effects for BDM and directed support at the AFRL EMP Sites (Trestle and Dipoles). In 1996, Nash left BDM and formed his own aerospace consulting business supporting many local and national aerospace companies, including consulting with Lockheed Martin on F-22 modernization.

An active AIAA member Nash served as the AIAA Antelope Valley Section Newsletter Editor. He later served twice as the chair for the AIAA Albuquerque Section, as well as being the Region IV Deputy Director for Finance and on the AIAA Membership Committee (1993–1999). He was a member of the Flight Testing Technical Committee and past chair of the International Membership Subcommittee. Nash received a 2003 AIAA Sustained Service Award and three Special Service Citations (1997, 1999, 2012).

A long-time member of the NM Professional Aerospace Contractors Association, he served as President, Program Chair, and Executive Board member for several years. He also served on the NM State University Aerospace Engineering Advisory Panel program to review their aerospace engineering program.

FACULTY OPENING
Stanford University
Department of Aeronautics and Astronautics

The Department of Aeronautics and Astronautics at Stanford University invites applications for a tenure track faculty position at the Assistant or untenured Associate Professor level.

Research advances in the fundamental areas of aerospace engineering are critical for future air and space transportation systems that will provide efficiency, safety, and security, while protecting the environment. We are seeking exceptional applicants who will develop a program of high-impact research, contribute to an innovative undergraduate curriculum, and develop graduate courses at the frontier of areas such as aerospace system design, autonomous vehicle technologies, and breakthroughs in aerospace propulsion concepts. We will place higher priority on the impact, originality, and promise of the candidate's work than on the particular area of specialization within Aeronautics and Astronautics.

Evidence of the ability to pursue a program of innovative research and a strong commitment to graduate and undergraduate teaching is required.

Candidates whose research programs in Aeronautics and Astronautics will involve the development of sophisticated computational and/or mathematical methods may be considered for an appointment with an affiliation with the Institute for Computational and Mathematical Engineering (**https://icme.stanford.edu/**).

All candidates should apply online at **https://aa.stanford.edu/job-openings**. Applications should include a brief research and teaching plan, a detailed resume including a publications list, three letters of reference, and the names and addresses of at least two more potential referees. Applications will be accepted until the position is filled; however, the review process will begin on January 1, 2019.

Stanford is an equal employment opportunity and affirmative action employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability, protected veteran status, or any other characteristic protected by law. Stanford also welcomes applications from others who would bring additional dimensions to the University's research, teaching and clinical missions.

UNITED STATES AIR FORCE ACADEMY

ASSISTANT PROFESSOR OF AERONAUTICAL ENGINEERING #18-58DFAN

The Department of Aeronautical Engineering anticipates hiring an Assistant Professor beginning June 24, 2019. The initial appointment will be for three years. Reappointments are possible. Applications are invited from candidates who can contribute to the United States Air Force Academy mission by interacting with cadets, both in and out of the classroom. Successful candidates will demonstrate the potential for teaching excellence, academic service, and sustained intellectual contributions in one or more of the following: aircraft structures, fluid dynamics, flight mechanics, airbreathing propulsion and aircraft design. Duties will include instruction ranging from introductory to advanced undergraduate engineering courses, research, academic advising, mentoring cadets, and fulfilling department duties and other service to the institution. An earned doctorate (completed no later than June 24, 2019) in Aeronautical Engineering, Aerospace Engineering, Mechanical Engineering or related field is required.

To Apply: Go to **www.usajobs.gov**. Type in "Professor" in the "Keyword" box and "Colorado Springs" in the Location box and click "Search." Scroll down until you locate this position.

Applications must be received by Dec 31, 2018. U. S. citizenship required.

AUBURN UNIVERSITY
SAMUEL GINNN
COLLEGE OF ENGINEERING

Senior and Open Rank Tenure-Track Faculty Positions

The Department of Aerospace Engineering at Auburn University invites applications for:

- A **senior rank** tenure-track or tenured faculty position (Associate or Full Professor) in **any area related to aerospace engineering**.
- An **open rank** tenure-track faculty position (Assistant, Associate or Full Professor) in **the general area of dynamics and controls** with an emphasis on aerospace applications.

All candidates will be expected to fully contribute to the department's mission through (i) the development of a strong, nationally recognized, funded research program, (ii) teaching at both the undergraduate and graduate level, and (iii) professional service. Successful candidates will have a demonstrated track record of scholarship, a creative vision for research, an active interest in engineering education, and strong communication skills. Senior level candidates will be considered for a prestigious Walt and Virginia Woltosz Professorship and will be evaluated on the strength and caliber of their existing research program along with their ability and desire to provide mentorship and leadership to a young, enthusiastic, and rapidly growing department. All candidates must have an earned Ph.D. in aerospace engineering, mechanical engineering or a closely related field at the time employment.

Candidates should log in and submit a cover letter, CV, research vision, teaching philosophy, and three references to:

Senior Rank Position:
http://aufacultypositions.peopleadmin.com/postings/3189;

Open Rank Position:
http://aufacultypositions.peopleadmin.com/postings/3140.

Cover letters may be addressed to:
Dr. Brian Thurow,
Search Committee Chair,
211 Davis Hall, Auburn University, AL 36849.

To ensure full consideration, candidates are encouraged to apply before December 1, 2018 although applications will be accepted until the positions are filled. The successful candidate must meet eligibility requirements to work in the U.S. at the time the appointment begins and continue working legally for the proposed term of employment. Additional information about the department may be found at: **http://www.eng.auburn.edu/aero/**

The Department of Aerospace Engineering at Auburn University is in the midst of unprecedented growth with undergraduate enrollment increasing by 40% in last 4 years to nearly 500 students. This growth has been complemented by aggressive faculty hiring with the department now consisting of 4 Full Professors, 9 Assistant Professors and 3 Lecturers. Our current focus is on the development of world-class research programs and growth of the graduate student body from its current size of over 50 students to a goal number of 100 graduate students within the next five years. The department is part of the Samuel Ginn College of Engineering, which has a total enrollment of over 6,000 students and is home to several nationally recognized research centers. Auburn University's proximity to the aerospace, defense, and government enterprises located from Huntsville, AL down to the Florida Space Coast presents a unique opportunity for the department to emerge from this growth phase as one of the premier aerospace engineering departments in the country.

Auburn University is one of the nation's premier public land-grant institutions. In 2019, it was ranked 52nd among public universities by U.S. News and World Report. Auburn maintains high levels of research activity and high standards for teaching excellence, offering Bachelor's, Master's, Educational Specialist, and Doctor's degrees in agriculture and engineering, the professions, and the arts and sciences. Its 2018 enrollment of 30,440 students includes 24,628 undergraduates and 5,812 graduate and professional students. Organized into twelve academic colleges and schools, Auburn's 1,450 faculty members offer more than 200 educational programs. The University is nationally recognized for its commitment to academic excellence, its positive work environment, its student engagement, and its beautiful campus. Auburn residents enjoy a thriving community, recognized as one of the "best small towns in America," with moderate climate and easy access to major cities or to beach and mountain recreational facilities. Situated along the rapidly developing I-85 corridor between Atlanta, Georgia, and Montgomery, Alabama, the combined Auburn-Opelika-Columbus statistical area has a population of over 500,000, with excellent public school systems and regional medical centers.

In support of our strategic plan, Auburn University will maintain its strong commitment to diversity with standards to help ensure faculty, staff, and student diversity through recruitment and retention efforts.

Auburn University is an EEO/Vet/Disability Employer

ASSISTANT PROFESSOR FACULTY POSITIONS

The Department of Aerospace Engineering and Mechanics at The University of Alabama invites applications for three assistant professor faculty positions. Areas of interest include, but are not limited to, computational and experimental solid mechanics, aerospace structures, and command (guidance and navigation) and control of UAVs. 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 position for command and control of UAVs will work closely with the Remote Sensing Center at The University of Alabama. The Center is a $6M/year international partnership among universities, industries, and governments to develop techniques and infrastructure applied to remote sensing of polar ice sheets, sea ice, ocean, atmosphere and land.

The University of Alabama currently enrolls over 38,000 students and employs over 1,700 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 MM Shelby Engineering and Science Quadrangle completed in 2014 and the newly reopened $22 MM renovated HM Comer.

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 positions are filled, with an expected start date of August 16, 2019. Electronic submission of application materials via The University of Alabama employment website is required (**facultyjobs.ua.edu**, requisition number 0811665). 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 Interim 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

1918

Dec. 1 With Bolshevik leader Vladimir Lenin's approval, professor Nikolai Zhukovsky, one of the world's foremost aeronautical pioneers, establishes TsAGI, the Central Aerohydrodynamic Institute in Moscow. TsAGI quickly becomes the primary aeronautical science and engineering institution in the newly formed Soviet Union. Andrei N. Tupolev, one of Zhukovsky's students at the Moscow Higher Technical School, joins TsAGI as its lead designer, thus embarking on a lifelong career creating military and civilian aircraft for the USSR. TsAGI continues today as the primary aeronautical research establishment of Russia. Sergei Leonidovich Chernyshev and G.S. Bushgens, **TsAGI: Russia's Global Aerospace Research Center. History of the Establishment and Future**, p. 20.

Dec. 4 Four Curtiss JN-4s start the Army's first transcontinental flight, leaving from San Diego. They arrive at Jacksonville, Florida, on Dec. 22. E.M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 9.

Dec. 12 The U.S. Navy's C-1 airship with a Curtiss JN-4 biplane suspended underneath lifts into the air above the Rockaway Naval Air Station on Long Island, New York. The aircraft is then released and flown back to the airfield. This is the first time that an aircraft was dropped from an airship. David Baker, **Flight and Flying: A Chronology**, p. 122.

Dec. 13-Jan. 16 A Royal Air Force Handley-Page, piloted by Maj. A.C.S. MacLaren, with Lt. Robert Halley and Gen. N.D.K. McEwen, as their passenger, makes the first England-to-India flight of 10,460 kilometers, arriving at Calcutta. **Aircraft Year Book**, 1920, p. 248.

1943

Dec. 13 In the largest air raid so far, 1,462 fighters and bombers strike Nazi targets in Hamburg, Kiel and Bremen, Germany. Approximately 1,000 bombers are escorted all of the way to and from their targets, providing much-needed fighter coverage to prevent the excessively high losses experienced during the unescorted raids against Regensburg and Schweinfurt earlier in the year. The new North American P-51 is introduced to combat and, with its exceptional range, is able to protect Allied bombers deep into German-held territory. Roger Freeman, **Mighty Eighth War Diary**, pp. 150-151.

Dec. 17 After several years of negotiations, President Franklin D. Roosevelt announces that the original 1903 Wright Flyer will return to the United Sates from the Science Museum in London, and will be donated to the Smithsonian Institution. The president makes the announcement during a dinner celebrating the 40th anniversary of the world's first airplane flight. Orville Wright had refused to give the flyer to the Smithsonian until the Smithsonian agreed that the Wrights and not former Secretary of the Smithsonian Samuel P. Langley built and flew the first airplane capable of flight. Smithsonian officials agreed thus opening the way for the return of the aircraft, which does not happen until 1948 because of the war. Michael Neufeld, ed., **Smithsonian National Air and Space Museum: An Autobiography**, pp. 40-45.

Dec. 24 German V-1 weapon sites under construction in the Pas de Calais area of northern France receive their first major assault, by 670 B-17 and B-24 bombers of the 8th Air Force. After the attacks, the Germans develop rapidly assembled prefabricated sites. K.C. Carter and R. Mueller, compilers, **The Army Air Forces in World War II**, p. 238.

1968

Dec. 3 President Lyndon Johnson presents the Harmon International Aviator's Trophy to U.S. Air Force Maj. William J. Knight for piloting the X-15 rocket research aircraft to a world record speed of 7,274 kph (Mach 6.7) on Oct. 3, 1967, making the X-15 the fastest plane ever flown, and this record for manned aircraft still stands. **Washington Post**, Dec. 3 , 1968, p. A7.

Dec. 4 The Eugen Sänger Medal of the German Society of Aeronautics and Astronautics is awarded in Bonn, West Germany, to the U.S. X-15 research team. Sänger was acclaimed as the first to define the potential of hypersonic rocket aircraft; he died in 1964. The award is accepted on behalf of the NASA-U.S. Navy-U.S. Air Force X-15 team by John V. Becker of NASA's Langley Research Center. NASA, **Astronautics and Aeronautics, 1968**, p. 300.

Dec. 5 NASA launches the 108-kilogram HEOS-A, for Highly Eccentric Orbiting Satellite, of the European Space Research Organization by a Thrust-Augmented Thor-Delta booster. HEOS, the European Space Research Organization's most advanced satellite and Europe's first deep-space interplanetary probe, contains eight onboard experiments designed by nine scientific groups in Belgium, France, West Germany, Italy and the United Kingdom to investigate interplanetary magnetic fields and solar and cosmic-ray particles outside the magnetosphere during a period of maximum solar activity. **New York Times**, Dec. 6, 1968; **Flight International**, Dec. 12, 1968, p. 1003, and Dec. 19, 1968, pp. 1040- 1041.

Dec. 7 The 1,995-kilgogram, 6.4-meter-span Orbiting Astronomical Observatory, America's heaviest and most complex unmanned spacecraft to date, is launched from Cape Kennedy, Florida, by an Atlas-Centaur rocket. It is the second of four such Earth-orbiting observatories and is to help measure ultraviolet radiation from stars in the Milky Way and other galaxies. **Flight International**, Dec. 19, 1968, p. 1042.

Dec. 11 The Fédération Aéronautique Internationale establishes its Yuri Gagarin gold medal honoring the Soviet cosmonaut who became the first man in space for his Vostok flight on April 12, 1961. The medal is to be awarded annually to the pilot contributing the best performance of the year in the peaceful exploration of space. NASA, **Astronautics and Aeronautics, 1968**, p. 309.

Dec. 15 NASA launches the ESSA 8 (or TOS-F) into a nearly polar, sun-synchronous circular orbit. It is the eighth weather satellite in the Environmental Science Services Administration's Tiros Operational Satellite system and is to provide global coverage of cloud patterns on a daily basis. **Washington Star**, Dec. 14, 1968, p. A-1.

Dec. 18 British Air Chief Marshal Sir James Robb, who served as Gen. Dwight Eisenhower's Vice-Chief of Staff during 1944-1945 and commander-in-chief of air forces in Western Europe from 1948 to 1951, dies at 73. He joined the British Army in 1914 and transferred to the Royal Flying Corps in 1916. Among other accomplishments, Robb helped establish the Empire Air Training Scheme from 1939, a massive training program that provided the Royal Air Force with trained aircrews from Canada, Australia, New Zealand and Southern Rhodesia. He was also the co-author of a volume of the official history of World War II, "Victory in the West" (1962). **Flight International**, Dec. 26, 1968, p. 1049.

Dec. 20 Flight No. 200 of the X-15 aircraft is canceled this day due to adverse weather conditions. The flight would have marked the completion of the X-15 flight research program. Therefore, NASA officially announces the program's completion, which ended with flight No. 199 made on Oct. 24 when NASA test pilot William H. Dana flew the X-15 N. 1 up to 76,200 meters and 5,925 kph (Mach 5.04). **New York Times**, Dec. 21, 1968, p. 73.

Dec. 21 NASA's Apollo 8, the second manned mission in the Apollo lunar program and first mission to orbit the moon, is launched from the Kennedy Space Center in Florida with a Saturn 5 vehicle, carrying astronauts Frank Borman, the

commander; James A. Lovell Jr., the command module pilot; and William A. Anders, the lunar module pilot. All objectives of the mission are met: demonstrating the performance of a lunar orbit rendezvous, including command service module navigation, communications and midcourse corrections; and command service module thermal and other mission activities. The Apollo 8 astronauts thereby become the first men to leave Earth's gravitational field and to enter into a temporary orbit around the moon. They also conduct the first TV transmissions of pictures of Earth from an altitude of 324,056 kilometers. On the fourth day, on Christmas Eve, communications are interrupted as the men become the first astronauts to see the far side of the moon. Thousands of images are also taken of the lunar surface and prospective landing sites are confirmed as satisfactory. On the fifth day and while completing the spacecraft's 10th revolution, a service propulsion system engine is fired that increases the spacecraft's velocity and propels Apollo 8 back to Earth, with a recovery made precisely on schedule in the Pacific Ocean, close to the recovery ship USS Yorktown on Dec. 27. **New York Times**, Dec. 22-28, 1968.

Dec. 31 The Tupolev Tu-144, the Soviet Union's first supersonic transport, makes its first flight from the Zhukovsky development facility near Moscow. This is two months before the Concorde and the plane is thus the first supersonic transport in the world to begin flight testing. It was also the first commercial transport to exceed Mach 2, on May 26, 1970. However, the TU-144 became a passenger carrier in November 1977, almost two years after Concorde, due to budget restrictions. **Aviation Week**, Jan. 6, 1969, p. 33.

1993

Dec. 4 China announces that it will rent payload space on forthcoming U.S. space shuttle missions for scientific purposes. NASA, **Astronautics and Aeronautics, 1991-1995,** pp. 444.

Dec. 2-13 One of the most important missions of the space shuttle program, STS-61 flown by the Endeavour, is undertaken to repair the Hubble Space Telescope. It is also the largest and most complex space repair so far. Among the seven-member crew's tasks is to upgrade Hubble's computer and install a new camera with corrective lenses. Swiss astronaut Claude Nicollier is part of this mission. The crew have trained for two years for the repair. By the end of the month it is confirmed that the mission has been a success. NASA, **Astronautics and Aeronautics, 1991-1995**, pp. 444-445, 449, 454, 707.

Dec. 13 Russia formally joins the U.S. as a partner in the International Space Station. Other partners are the European Space Agency, Japan and Canada. NASA, **Astronautics and Aeronautics, 1991-1995**, p. 447.

Dec. 18 Thaicom 1 (also known as DDS-1), Thailand's first domestic satellite and the first Dual Direct Broadcast satellite is launched by an Ariane rocket. Boeing, **Thaicom fact sheet**.

ANDREW BANNER, 30

Scaled Composites design engineer

As a child, Andrew Banner's experiments with various configurations of throwable gliders made of balsa wood taught him how the center of gravity affects aircraft stability. In sixth grade, Banner bought his first radio-controlled aircraft, an electric flying wing that crashed multiple times before he acquired a radio-controlled trainer airplane that was easier to fly. After college, Banner immediately went to work at Scaled Composites, the 506-person Mojave, California, company founded by Burt Rutan, the aerospace engineer famous for innovative designs. There, Banner works on Stratolaunch, the gigantic, twin-fuselage carrier aircraft Scaled is building to air-launch rockets.

How did you become an aerospace engineer?

From a very young age, I wanted to be an inventor and I always had a passion for aircraft. Throughout high school I designed and built numerous radio-controlled planes. By this time, I knew that an inventor was really an engineer. When I entered the University of Washington, I took the math and science prerequisites for engineering classes. Junior year, I was admitted to the Department of Aeronautics and Astronautics. During my senior design course, I co-led a team of 30 students performing a conceptual design of a large high-aspect-ratio transport aircraft and a detailed design we built and flew of a 3.6-meter-wingspan unmanned version of the aircraft. I knew of Burt Rutan and Scaled Composites' unique aircraft and applied shortly after graduating in 2012. I have been working at Scaled ever since. I started on the Stratolaunch program, which will produce the world's largest aircraft by wingspan and the second largest by maximum takeoff weight. Needless to say, this was an intimidating project to be put on fresh out of school. My first task was determining how to fixture the fuselage and the sequence for building it. Then, I moved on to aircraft part design within the wing group. I led the Pegasus project for Scaled while concurrently working with the wing group. I currently lead a team of 10 engineers designing and building the Stratolaunch aircraft fuselage.

Imagine the world in 2050. What do you think will be happening in aviation?

As fuel prices keep increasing, I expect to see the first blended wing-body transport aircraft start moving the masses around the world. I am also hopeful that the return of supersonic transport will happen utilizing quiet supersonic technology and there will be a revolution in light aircraft powered by electric propulsion. By 2050, I'd expect to see a second space race, one fought by companies instead of governments. We might see the first people taking steps on Mars and exploring the red planet. It is an exciting time to work in aerospace. Aircraft and spacecraft have looked nearly the same for the last 30 years, and I think the industry is ripe for change in the next 30. ★

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