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AEROSPACE

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2017

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THE YEAR IN REVIEW

The most important developments
as described by AIAA's technical
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- Energy-Efficient and Renewable Energy Technologies
- Fossil-Fuel Power Technologies
- Gas Turbine Engines
- High-Speed Air-Breathing Propulsion
- Hybrid Rockets
- Inlets, Nozzles, and Propulsion Systems Integration
- Liquid Propulsion
- Nuclear and Future Flight Propulsion
- Pressure Gain Combustion
- Propellants and Combustion
- Propulsion and Power of Unmanned Aerial Systems
- Propulsion Education
- Small Satellites
- Solid Rocket Propulsion
- Space Nuclear Power Systems
- Space Solar Power
- Thermal Management Technology

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propulsionenergy.aiaa.org


Shaping the Future of Aerospace

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A Bombardier conceptual design engineer talks about working on the C Series.

The angel in the details

On its surface, our annual Year-in-Review special issue adds up to a compendium of the nitty-gritty aerospace engineering and scientific work accomplished in 2017. We depict the often-unsung research that will make it possible for this community to continue achieving astounding operational breakthroughs, such as SpaceX reusing a rocket stage for the first time, as it did in March.

Consider for example the descriptions of novel aerodynamic measurement techniques on Page 17 or the efforts described on Page 10 to turn the uncertain wind responses of rotorcraft into a predictive tool. These and many other projects will empower engineers of the future to achieve extraordinary breakthroughs in the years ahead.

Illuminating that kind of work is one reason this issue is valuable, but I see another reason, too. These pages provide a glimpse into the aerospace technology culture for students or those who work on the fringes of the community or even outside of it. Members of this community value data, knowledge, problem-solving and professionalism. The best of them share data and insights as much as possible. They publish articles in AIAA's technical journals. They attend AIAA forums. They participate on technical committees. They volunteer to write articles for this special issue. They are passionate, but also fact-based. This is not to make a claim that all is perfect in this community, but these pages demonstrate that the trajectory is sound. Outliers are rare. In the years ahead, I'm confident we'll see even more workforce inclusiveness and diversity in the aerospace profession in the U.S. and abroad, and this will fuel even more advances.

It's refreshing to pause at the close of a tumultuous political year to remember what humans can accomplish when they operate in a culture that values respect and dedication to facts. Some of those involved in the research in these pages will no doubt shift out of engineering at some point in their careers, and they will take these values with them. Some will become business executives, entrepreneurs or leaders in government agencies. Some might even dare to enter politics. Of the 535 lawmakers in the U.S. Congress, just eight have engineering backgrounds, according to the Congressional Research Service, which analyzed Congressional Quarterly's "Member Profiles." It shows.

More than once as I read the articles for this special issue, I wondered, "How did they even think to try that?" Innate human creativity and originality partly explain things, but those attributes can flourish only when a culture lets them. What you see in these pages is an aerospace culture that's starting to fire on all cylinders. That should make us optimistic about 2018. ★

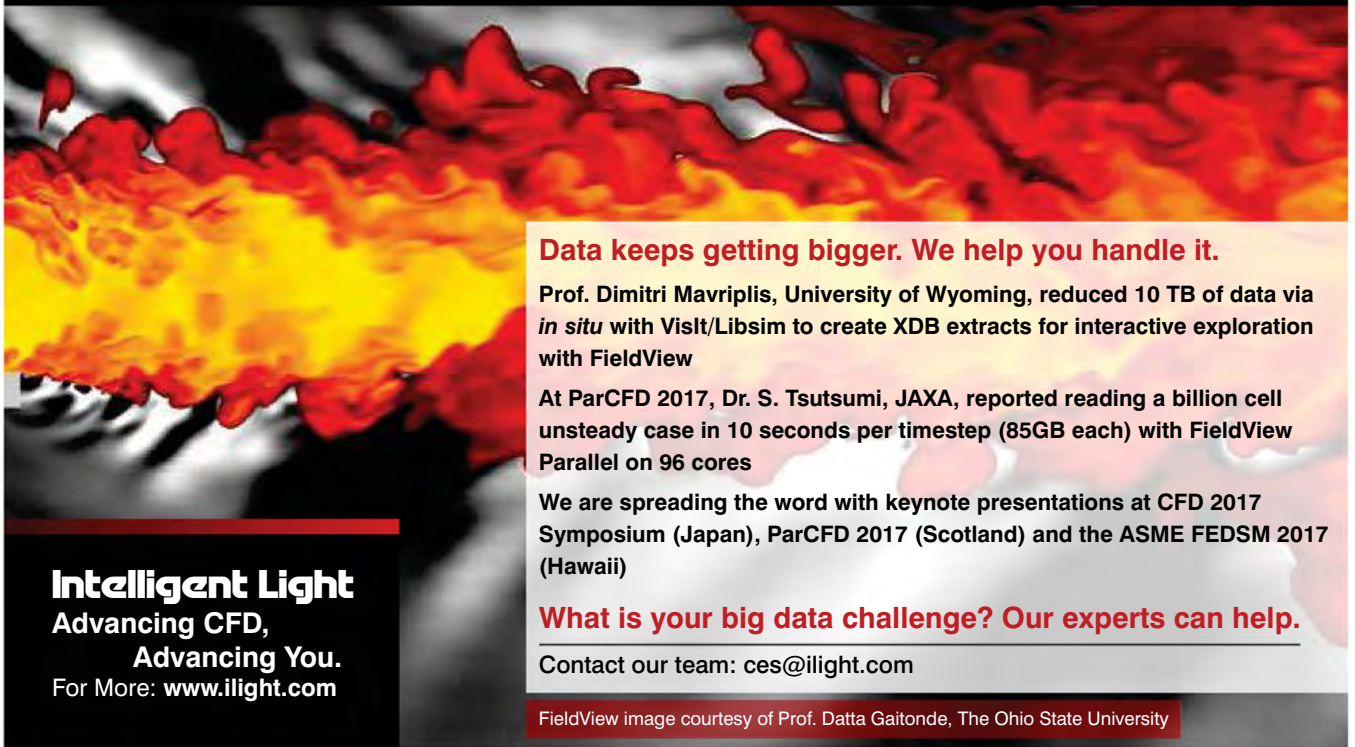
▲ This CREATE-AV Kestrel simulation

predicts aerodynamic loading during difficult maneuvers. The colors in the wake of the aircraft are the vortical disturbances created due to aerodynamics and engine exhaust.



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

Intelligent Light 2017 Year in Review



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FieldView image courtesy of Prof. Datta Gaitonde, The Ohio State University

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AIAA
Shaping the Future of Aerospace

A Year of Change

It has been a very busy year for the Institute. Through the hard work of our volunteer leaders, members, and staff, AIAA is focused, financially strong, and poised to provide our members the programs, content, and leadership that will help the aerospace sector grow and thrive as a global enterprise. It has also been a year of change on many levels, changes that I believe will help the Institute continue to grow, flourish, and serve you—and the aerospace community—even better.

This is always one of my favorite issues of Aerospace America. Reading about all the amazing things being done in the aerospace community by AIAA members is eye-opening and inspirational. In that spirit I wanted to share with you some of the Institute's highlights of the past 12 months.

The biggest institutional change was our formal transition to AIAA's new governance structure which began in May. We transitioned from a single Board of Directors to a new Board of Trustees and Council of Directors. This structure allows for the addition or deletion of both Board-directed or Council-directed committees and groups as the evolving vision and strategic plan of the Institute dictate. The member-directed committees under the Council of Directors will generate ideas to shape our future vision and strategy and will then communicate those ideas to the Board through the Council. The Board will weigh those suggestions and will set the Institute's strategic vision as well as develop a Strategic Plan to achieve the vision. The Board-directed committees supported by the professional staff will create and execute the plans necessary to implement the Institute's strategy and vision. The Board will oversee this entire process and will monitor our collective progress.

On 1 June, the new digital edition of Aerospace America, AerospaceAmerica.aiaa.org, debuted. This welcome change to our online presence was the result of a multiyear modernization effort that began with the print redesign that debuted in September 2016. Since then, the magazine has garnered multiple regional and national awards.

The ongoing need to offer AIAA's members engaging and relevant programming as well as expand the scope of the aerospace profession into adjacent but critical technology areas drove another major effort—the continued refinement and expansion of our growth plan. The elements incorporated into the plan this year focused on commercialization of space, aerospace cybersecurity, and unmanned aerial systems (UAS) and autonomy.

Our planned second Space Commercialization Executive Summit was dealt a blow by the unprecedented cancellation of the 2017 AIAA SPACE Forum because of Hurricane Irma, but we have rescheduled it to coincide with the 2018 SciTech Forum.

Building upon the slow but steady emphasis on the critical

challenge of cybersecurity in aerospace, AIAA took several deliberate steps in 2017 to inform and assist the industry. These focused on understanding the myriad threats and threat actors, and the management and mitigation of such threats. To that end, we've been publishing Protocol: Aerospace Cybersecurity News, a monthly e-newsletter available to all members. Also, at our 2017 AVIATION Forum, we held a cybersecurity workshop aimed at educating aerospace professionals about the very real cyber threats that could adversely affect their businesses or organizations.

And we are providing a new and direct benefit to our valuable corporate members. In August AIAA in partnership with TruSTAR launched the AIAA-TruSTAR Threat Intelligence Exchange. Corporate member participation in the exchange will enable companies to enhance incursion investigation and mitigation, collaborate and share information and best practices, and access actionable content. We are pleased that three AIAA corporate members have already joined the exchange.

In terms of UAS and autonomy, we hosted a second successful DEMAND for UNMANNED symposium as a part of the 2017 AIAA AVIATION Forum. In addition, AIAA, as you may know, is a proud sponsor of the Intrepid Sea, Air, & Space Museum's Drones: Is the Sky the Limit? exhibit in New York City. Specifically, AIAA supports the In the News interactive education station created by The Center for the Study of the Drone at Bard College.

The Institute has been quite active in the public policy arena. Associate Fellow Mitchell L.R. Walker of the Georgia Institute of Technology and I testified in two separate hearings before the House Subcommittee on Space. AIAA also partnered with sister societies to hold multiple widely-attended briefings: in January new House and Senate staffers were provided with an overview on "Aerospace 101" and in September House staff were briefed on the importance of government investment in aerospace research and development. Lastly, the Public Policy Committee reestablished the August for Aerospace program where several sections across the nation engaged their local elected officials in various outreach activities.

Heraclitus said, "The only thing that is constant is change" and I, for one, look forward to the year ahead and the positive changes it will bring. Here's to a bright future—for the Institute and the aerospace industry. ★



Sandra H. Magnus, AIAA Executive Director

Testing a variety of adaptive structures

BY DARREN J. HARTL

The **Adaptive Structures Technical Committee** supports work to enable aircraft to adapt to changing environmental conditions during flight.

NASA's Transformative Aeronautics Concepts Program in April chose Texas A&M University to lead an effort to explore adaptive airframe concepts based on shape-memory alloy, or SMA, actuators for **reducing sonic boom noise levels across changing flight conditions**. The work is part of NASA's University Leadership Initiative. At the same time, a second team that includes the University of Tennessee, Texas A&M, Rutgers University and others was chosen to demonstrate the viability of ultra-efficient wing design based on such adaptive structures concepts as slotted airfoils and active trailing edges driven by piezocomposite smart material actuators, developed at Rutgers over the past year. Boeing is a primary industrial partner on both of these University Leadership Initiative efforts.

Morphing aircraft remained one of the most active topics this year. NASA's Armstrong Flight Research Center in California and the Air Force Research Laboratory in Ohio partnered throughout 2017 to perform a series of flight tests at Armstrong on an Adaptive Compliant Trailing Edge to investigate **flexible trailing-edge wing flaps** as a means to improve aerodynamic efficiency and reduce noise. The experiments collected flight data regarding integration and reliability of the new compliant flaps manufactured by FlexSys.

Armstrong also teamed with Boeing throughout 2017 to investigate in-flight wing folding for aircraft fuel cost reduction. The **Spanwise Adaptive Wing project** this year completed vehicle ground-testing on Area-I's PTERA, a subscale, unmanned aircraft shaped like a Boeing 737. SMA actuators in a compact folding mechanism accommodated within the wing outer mold line promise to save weight and greatly reduce complexity relative to alternatives. Next, flight tests will be performed with PTERA in which the folded wing tips will provide 40-50 percent of the yaw control currently provided by the rudder. Wing morphing was also addressed in 2017 at TU Delft, where continuous camber and twist induced along wing trailing edges are being explored in prototypes



NASA

with novel mechanisms that reduce actuation energy and wing skin strain.

Researchers at AFRL at Wright-Patterson Air Force Base in Ohio demonstrated several adaptive structures and multifunctional materials concepts this year. The Aerospace Systems Directorate proved the utility of multimaterial 3-D printing as a tool for fabricating aeroelastic wind-tunnel testbeds. This was done in the early months of 2017 by demonstrating flutter testing to failure, model revision, refabrication and follow-on testing within one week for under \$2,500 per model, all within the speed constraints of conventional low-speed wind tunnels. Partnering with the Materials and Manufacturing Directorate, this team also developed liquid crystal elastomers that can be patterned such that out-of-plane surface topography is generated upon actuation from a flat state. Potential applications of this experimentally validated capability include vortex generators and distributed roughness elements for decreasing drag and increasing stability control. Working with engineers at Texas A&M in January and February, AFRL composites experts also designed and fabricated an array of structurally embedded vascular antennas consisting of reconfigurable liquid metal traces embedded within composite wing leading edges.

New adaptive space structures were also developed and demonstrated in 2017. In February, the AFRL Space Vehicles Directorate launched an external piezoelectric wafer active sensor experiment that was installed on the external payload platform of the International Space Station for the purposes of structural health monitoring. In January, Texas A&M and NASA's Johnson Space Center teamed up to complete demonstration of a prototype shape-memory alloy-based morphing composite radiator for crewed spacecraft in a relevant space environment, proving that passive and highly adaptive thermal control is possible and enabling difficult space exploration missions to come. ★

▲ **The Spanwise Adaptive Wing project** being led by NASA and Boeing is working to devise a shape-memory alloy that will bend the tips of a plane's wings in flight, improving aircraft performance and fuel economy.

From commercial to X-planes, a year of design progress

BY 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.

► **Researchers at Virginia Tech** designed the flexible wings of this approximately 50-percent scale version of NASA's X-56A to minimize weight and maximize aerodynamic efficiency. Team members from the University of Minnesota built the plane.



Rakesh Kapanaia/Virginia Tech

In June, Mike Delaney, vice president and general manager of airplane development at Boeing Commercial Airplanes, gave Aviation Week & Space Technology a succinct description of the importance of multidisciplinary design optimization: “Using multidisciplinary design optimization and model-based systems engineering, Boeing is closely analyzing the design, construction and testing of the new midsize airplane in advance of any formal go-ahead decision. Today we are very early in a program that’s not launched, and we already know what the production system looks like.”

This year, MDO impacted aerospace R&D through NASA’s **OpenMDAO**. This software was used in new studies, including coupled propulsion-power-thermal-trajectory analysis for NASA’s X-57 experimental aircraft and fully coupled propulsion-aerodynamic simulation of a boundary-layer ingestion tail-cone-thrust configuration.

The European CleanSky2 Initiative’s **Modeling and Simulation Tools for System Integration on Aircraft project**, called MISSION for short, developed and demonstrated a simulation environment to harmoniously integrate different models and tools. MISSION combines MDO methodologies and model-based system engineering to develop an integrated framework for design, development and validation of aircraft systems.

Academic researchers made important steps this year to advance the robustness and applicability of MDO methods. One challenge is that complex simulations often produce inaccurate sensitivities. To address this, in August, Rensselaer Polytechnic Institute developed a **novel gradient-based algorithm for noisy or inaccurate data**. Another challenge is

managing disparate multidisciplinary data sources in the design process. In August, McGill University Systems Optimization Lab presented methods for adequacy-based management of model ensembles in optimization. An Air Force Office of Scientific Research Multidisciplinary University Research Initiative led by MIT plans to publish a toolbox of methods for multi-information source management, including Bayesian optimization methods from Cornell, Santa Fe Institute and MIT, at the Conference on Neural Information Processing Systems in California in December. The team also developed sequential information source fusion, led by Texas A&M.

Topology optimization presents another exciting area. The Multiscale, Multiphysics Design Optimization Laboratory at the University of California, San Diego, in July developed a multiscale optimization framework that simultaneously optimizes an integrated material and structural system. This links directly with rising interests in **integrated computational materials engineering**. Southampton University developed methods and software for design optimization in the presence of topological variations, with application to gas turbine combustion systems and rapid optimization of aircraft across ranges of topologies.

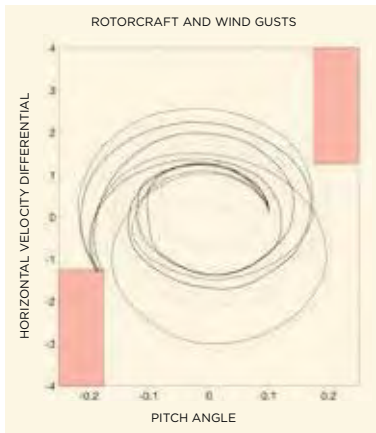
New applications in MDO highlight emerging opportunities for improving system design processes. The Design and Optimization of Energy Systems Laboratory at the University of Texas, Dallas, applied MDO to the design of lithium-ion battery thermal management systems in electric vehicles; University of Illinois Engineering System Design Lab investigated co-design of wind farm layout and control design. The Multidisciplinary Analysis and Design Center for Advanced Vehicles at Virginia Tech is collaborating with University of Minnesota, Aurora Flight Sciences, STI Inc., DKS and Associates, and CMSoft to optimize X-56 type aircraft under NASA’s Performance Adaptive Aeroelastic Program. The team has fabricated and was making plans to initiate flight testing of a 50 percent scale X-56 model to study active control of flexible aircraft.

Georgia Tech developed **FUNtoFEM**, a high-fidelity aeroelastic coupling framework for NASA’s FUN3D code, for adjoint-based MDO of fixed-wing or rotorcraft configurations. The University of Michigan developed **OpenAeroStruct**, an open-source low-fidelity wing aerostructural optimization tool. OpenAeroStruct was used for educational purposes in MDO courses and served as a benchmark for research on coupled system solvers, MDO architectures and uncertainty quantification. The University of Michigan and NASA developed the **uCRM**, an open model for high-fidelity aerostructural studies based on NASA’s Common Research Model, which is representative of long-range twin-aisle transport aircraft. ★

Applying uncertainty quantification to complex systems

BY PHIL BERAN

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



▲ By studying uncertain rotorcraft responses to winds, researchers working under DARPA's Scalable Inference for Rare Events, or SIRE, project are learning to predict when wind gusts will pose a danger to rotorcraft. The pink regions depict danger zones.

United Technologies Research Center

The aerospace community faces a demand for better approaches to evaluate the non-deterministic and complex behavior of highly integrated aerospace systems reflecting real-world uncertainties. Two organizations that stepped up this year to meet that need were DARPA, which is funding the development of scalable uncertainty quantification methods for design of defense-related systems, and NASA, which is sponsoring a research team to understand how to fuse uncertain information sources into an air traffic management system.

Teams sponsored by DARPA's **Enabling the Quantification of Uncertainty in Physical Systems** program made significant progress in 2017 in demonstrating scalable uncertainty quantification methods for system design. Several teams demonstrated scalability for aerospace problems, including SEQUOIA, or Scalable Environment for Quantification of Uncertainty and Optimization in Industrial Applications, which studied embedded engine nozzles; QUANTUM, a nickname for Inference, Simulation and Optimization of Complex Systems Under Uncertainty, which focused on turbulent jets; and SIRE, or Scalable Inference for Rare Events, which researched rotorcraft. The DARPA program aims to improve understanding of how uncertainties impact complex physical systems and to exploit this understanding to improve design. The DARPA-funded teams are tackling fundamental mathematical barriers to permit large numbers of uncertain input parameters and to account for uncertainties inherent in the large, nonlinear models used in realistic, multi-physics engineering problems.

In June, **SEQUOIA discovered new engine nozzle shapes that robustly boosted thrust performance without adding significant weight.** The SEQUOIA team is designing lightweight engine nozzles subjected to aerodynamic, thermal and structural uncertainty using model reduction, embedded model-form discrepancies and multilevel, multifidelity techniques for propagation, inference and design. That team includes Stanford Universi-

ty, Sandia National Laboratories, the University of Michigan and the Colorado School of Mines.

The researchers on team QUANTUM in August **demonstrated a new way to solve an optimization under uncertainty problem for a turbulent jet with 1 million uncertain parameters** by developing scalable, multifidelity uncertainty quantification methods to compute failure probabilities. They optimized horizontal velocity profile at the jet inlet boundary to maximize expected downstream jet width, while accounting for turbulence model uncertainties, and developed a control strategy to maintain performance and mitigate negative consequences of modeling inadequacies. The QUANTUM team includes the University of Texas at Austin, Caltech, Rice University and MIT.

The SIRE team of DARPA-funded researchers in August **discovered rare rotorcraft pitch failures through a new dynamic, importance-sampling approach based on transport maps.** The SIRE team includes researchers from the United Technologies Research Center and MIT. By investigating the non-deterministic response of a rotorcraft subject to uncertain gusts modeled as Ornstein-Uhlenbeck processes, the SIRE team aims to predict impending rotorcraft failure using streaming data in an online Bayesian setting.

NASA in June began sponsoring a five-year research center, led by Arizona State University, to **study the safe integration of uncertain data sources in a dynamic, air traffic management system** with the aim of influencing the FAA's NextGen Air Transportation System. The research team, funded by NASA's Aeronautics University Leadership Initiative, includes Vanderbilt University, Southwest Research Institute and Optimal Synthesis Inc. The center will investigate the dynamic and uncertain nature of human-cyber-physical interactions in air traffic management, which has not been previously explored from a system modeling perspective.

Researchers also extended the ability of non-deterministic approaches to unite multiple information sources. This exploration sought to reduce high computational costs by leveraging cheaper information sources. In research reported by the University of Dayton in July, locally optimized surrogate models were constructed and applied to aircraft design spaces. Research at Wright State University recast the Kriging method in a non-deterministic and non-stationary framework to manage uncertainties in models with different fidelities. In July, Wright State and Air Force researchers applied this framework to improve the effectiveness-based design of an aircraft under mission uncertainty. ★

Contributors: Karen Willcox, Harok Bae, Corey Fischer, Yongming Liu, and Markus Rumpfkeil



NASA

partnering with small businesses and an annual design competition for undergraduate and graduate students called the **2018 Breakthrough, Innovative, and Game-changing Idea Challenge**.

A project that aims to answer the electricity needs of human space exploration was also put to the test in June, when the International Space Station's robotic arm facilitated the unfurling of the photovoltaic cells mounted on a composite fabric called the **Roll Out Solar Array, or ROSA**.

ROSA operated June 17-25 so the Air Force Research Laboratory, which is leading the experiment, could measure its behavior and power production performance in the combined microgravity and extreme thermal environment of space. Unlike existing rigid panel solar arrays, ROSA shrinks mass by 33 percent and takes up 400 percent less volume during storage when rolled up. On June 18, ROSA unfurled under the power of the stored strain energy in the composite slit-tube booms, a thin mesh blanket of photovoltaic cells into a stiff solar sheet. It operated nominally even after 10 months of storage, launch and 215 on-orbit thermal cycles. The Department of Defense Space Test program, NASA and Deployable Space Systems Inc. are partnering with AFRL on this project.

The NASA-funded Jet Propulsion Laboratory and the Indian Space Research Organization are also prepared to complete critical design reviews in November of key parts for its joint radar project to monitor changes in the Earth's cryosphere, ecosystem and surface. The **NASA-ISRO Synthetic Aperture Radar mission**, which passed its preliminary design review in 2016, aims to keep a watchful eye on Earth with a dual frequency L-band and S-band polarimetric radar. India will provide a geosynchronous satellite launch vehicle with a 4-meter fairing, an I-3K spacecraft bus and the S-band radar electronics. NASA will assemble the radar payload, which includes the Radar Instrument Structure, L-Band radar electronics and the radar antenna. The antenna includes the S and L patch antenna arrays, a 9-meter deployable boom and a 12-meter deployable mesh reflector to serve as the RF aperture for both frequencies. The reflector and the boom assemblies had been poised to complete their reviews in November as a key step toward flight production. The spacecraft has a proposed launch date of December 2021.

The Spacecraft Structures Technical Committee's **Handbook of Testing Large, Ultra-Lightweight Spacecraft**, slated for publication by AIAA in late 2017, will provide both the theory and especially the practice of testing these unique spacecraft for project managers and technical specialists. ★

Interest grows in deployable structures

BY JEREMY BANIK, RICHARD PAPPA AND MEHRAN MOBREM

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

▲ **The Roll Out Solar Array** was deployed from the International Space Station during a June 17-25 test.

Astronauts need enough electrical power to operate a base camp on the surface of Mars — as well as stay warm and connected with Earth — so NASA's structures and power experts spent 2017 developing concepts for large lightweight deployable solar arrays for the surface of the red planet.

Experts from NASA's Langley Research Center and Glenn Research Center began working on solar array concepts in October 2016 and aim to continue their design work in 2018. Type 1 arrays with about 1,000 square meters of area would deploy from Mars surface landers to supply 10 kilowatts of nighttime electrical power and 50-80 kilowatts of daytime electrical power near the equator, depending on the seasonal factors on the Martian surface. NASA is also eyeing how to develop Type 2 arrays that are easily transported from landers to remote sites to recharge human-occupied rovers and Type 3 solar arrays with flexible packaging that can squeeze into unused spaces on landers for emergencies. The project is

Exceptional year for R&D in structural dynamics

BY D. TODD GRIFFITH AND NATHAN FALKIEWICZ

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

There was much activity in Europe as the **first phase of the Clean Sky Program** drew to a close, focusing on experimental demonstrations of breakthrough technologies in advanced aerodynamics and in loads control and alleviation.

Key tests included those in early 2017 on the **Experimental Transonic Investigations on Laminar Flow and Load Alleviation**, or ETRIO-LLA, demonstrator, a 5.8-meter scaled wing model tested in the ONERA S1 tunnel in Modane, France, in early 2017. This model demonstrated an extended natural laminar flow region at the cruise design point of Mach 0.74. The model was also equipped with trailing edge loads control devices to effect drag reduction in off-design steady conditions at different points in the flight envelope.

Project GLAMOUR, short for **Gust Load Alleviation Techniques Assessment on Wind Tunnel Model of Advanced Regional Aircraft**, demonstrated active gust loads alleviation using a unique half aircraft model (2.8-meter semi-span), with multicontrol surfaces on the wings and tail, manufactured and tested at the Politecnico di Milano in Italy. Of particular note was the ability to enable pitch and plunge motions using a

specially designed control system and also the use of bespoke gust generators. Several novel control algorithms were developed, and it was concluded that gust loads alleviation technologies are going to be very important for the next generation of transport aircraft.

The Lincoln Laboratory at the Massachusetts Institute of Technology in April completed a system-level vibration test campaign on the cameras and associated hardware for TESS, the **Transiting Exoplanet Survey Satellite**, which is slated for launch in March 2018. TESS is an Explorer-class

planet finder and will conduct the first spaceborne all-sky transit survey. The principal goal of the mission is to detect small planets with bright host stars in the solar neighborhood. The test campaign included subjecting the hardware to both sine and random vibration environments to demonstrate the hardware's capability to withstand launch loads. A variety of real-time limit criteria were implemented, including force limits at the base and response limits at various points across the structure. Compliance with traditional random vibration environments, limit load criteria and angular acceleration requirements was achieved through a combination of testing and analysis. The program is led by the MIT Kavli Institute with NASA's Goddard Space Flight Center in Maryland providing program management and Orbital ATK supplying the spacecraft and mission operations support.

In the launch vehicle area, **structural testing of large segments of NASA's Space Launch System** is providing engineers with confirmation of vehicle design parameters to assure future mission success. In June, one such segment, the Integrated Spacecraft and Payload Element, completed four months of testing. The primary objective of the ISPE testing was the measurement of stresses and internal loads throughout the full assembly as predicted external flight loads were applied. Secondary objectives involved measuring modal responses — how the structure reverberates in response to being shaken and tapped. These modal responses were then compared to predictions from math models, and where necessary, the math models of the ISPE components were adjusted to match the test results. The updated math models will be used in the next loads analysis cycle of the complete SLS vehicle to provide more accurate vehicle-level loads predictions. The SLS program is led by NASA's Marshall Space Flight Center in Alabama.

A newly formed strategic partnership between Airbus and the University of Michigan led to establishment in June of a **center to investigate new methods and computational techniques for designing and evaluating future aircraft configurations**. The new Airbus-University of Michigan Center for Aero-Servo-Elasticity for Very Flexible Aircraft will develop new computational tools that will explore new design options and reap the benefits of long wingspan configurations while mitigating the new aero-servo-elastic challenges. The fundamental research questions being addressed explore new uncharted territory in commercial transport aircraft configurations while developing the appropriate computational methods, algorithms and tools. ★

▼ **Natural laminar flow** and passive loads alleviation was demonstrated this year using a semi-span wing in a wind tunnel operated by ONERA, the French national aerospace research center. The tests were carried out under project ETRIO-LLA, short for Experimental Transonic Investigations on Laminar Flow and Load Alleviation.





University of Pisa

Structures small to large 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

▲ PARSIFAL, short for PrandtlPlane Architecture

for the Sustainable Improvement of Future Airplanes, is a project focused on developing a boxed wing structure for commercial and passenger traffic. Here is an artist's rendering of a prototype PrandtlPlane.

The Air Force Institute of Technology in Ohio this year continued research on a lighter-than-air-vehicle that has an internal vacuum. A 1.5-meter-diameter vehicle was designed using graphene and nano composite material. Another AFIT project related to the design of a projectile using additive manufacturing material. The projectile was optimized to create the maximum energy at impact with a target. The specimen was tested and the results were very favorable. Another project related to the investigation of an airfoil undergoing flutter and chaotic behavior, and yet another considered the effect of laser shock penning on the residual stresses surrounding a crack. Work was also done associated with an improved Goodman Diagram for the evaluation of material endurance limits.

Turning to space launch, NASA in May announced completion of a series of structural tests on the Space Launch System upper stage and adapters at Marshall Space Flight Center in Alabama. The initial SLS configuration will have a minimum 70-metric-ton lift capability and be powered by twin solid rocket boosters and four RS-25 engines.

In Europe, researchers this year announced European Commission funding for an effort called PARSIFAL, short for PrandtlPlane Architecture for the Sustainable Improvement of Future Airplanes. It is a joint venture with San Diego State University. This breakthrough innovation project is coordinated by the University of Pisa in Italy and funded under the Horizon2020 Program. Researchers aim to demonstrate how the adoption of a boxed-wing structure, known as a PrandtlPlane, can bring significant improvements for air transportation. Among

the challenges of the study is the design of an aircraft that must satisfy the increasing amount of passenger traffic and at the same time drastically reduce noise and emissions while increasing safety and comfort in flight. Researchers plan to demonstrate that the PrandtlPlane configuration is flexible and may be used for both the transport of passengers and cargo in a wide range of missions. Additionally, the project is to develop scaling procedures to look into the possibility of applying the PrandtlPlane configuration to aircraft of different dimensions and payload capabilities, including both regional aircraft and ultra-large aircraft, bigger than an A380, for instance.

DARPA in March awarded Boeing a \$146 million contract for its Experimental Spaceplane or XS-1 program. Boeing's design, called Phantom Express, will have advanced capabilities such as autonomous flight, agile launch and reusable propulsion systems. It could revolutionize the U.S. satellite launch process for both military and commercial programs. With a wing span of 19 meters, Boeing's Phantom Express would lift off like a rocket, release its payload into orbit and return to the launch site like an airplane. It would enable rapid, on-demand, low-cost access to space. DARPA has approved progression to Phases 2 and 3, which are fabrication and flight. At Phase 3 in 2020, Phantom Express is expected to demonstrate its capability to carry up to 1,360 kilograms into low Earth orbit 10 times in 10 days. Its reusability is projected to lower the current recurring costs by a factor of 10 to as little as \$5 million per flight.

Mississippi State University, University of Illinois at Urbana-Champaign and Israel Military Industries worked on a program to develop analytical and experimental protocols for the characterization of viscoelastic materials in real time. Both quasi-static and dynamic experiments are performed. The possible influences of material nonlinearities are also being investigated. ★

Contributors: Anthony N. Palazotto, Bruce Willis, John Zappay, Luciano Demasi, Zhenning Hu

Surviving fragment impacts, fires

BY AMEER G. MIKHAIL, ALEX G. KURTZ, AND ADAM E. GOSS

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

To more accurately assess the vulnerability of aircraft, the U.S. Air Force Research Laboratory at Wright-Patterson Air Force Base in Ohio this year focused efforts on fast and accurate modeling of the fragmentation patterns and the front and rear flash duration and intensity of the flash fires that occur when a steel fragment impacts an aluminum plate representing the surface of an aircraft. The overarching objective of this multiyear project is to generate data, perform shock physics modeling and simulation, and develop **algorithms for the fragment flash for accurate predictions of aircraft vulnerability to fragment threats and fires**. High-speed cameras and laser imaging techniques record the impacts for analysis. The project is being executed in conjunction with a fuel spurt study, which together support an overarching Next Generation Fire Model, or NGFM, initiative.

In conjunction with the fragment flash research and in support of the overarching NGFM initiative, the Air Force Hydrodynamic Ram Spurt Model Development and Validation program is developing an understanding of the fundamental physics associated with ballistically induced, hydraulic ram fuel spurts. This year, the Air Force NGFM initiative funded and initiated the fuel spurts fast modeling and analysis effort with the accompanying needed tests and data for validation of the spurts model. Through physics-based modeling and underpinned with empirical test data and statistical analyses, the developed mod-

ule will ultimately lead to the development of a fast tool ultimately integrated with higher-level vulnerability assessment codes. This program is in the startup phase and is developing a detailed program plan.

In the maintenance and repair area, the Air Force Expedient Repair program focuses on **assessing and demonstrating fast repair techniques that can be carried out in the field on composite airframes** with results that will last until the next maintenance cycle. Over the course of several months, the maximum repairable area size of a particular composite surface damage was investigated. The objective is to improve allied-nation interoperability while meeting aircraft availability demands. The Air Force, NATO allies and other organizations are participating in this ongoing program. The goal is to advance the maturity of expedient repair concepts to where they are pre-approved for application to limited damage sizes within certain aircraft zones. The effort focuses on discovering new techniques that improve operational aircraft performance through restoring full operational capability of the composite structures while reducing repair costs. Participating organizations seek to improve expedient repair ease and effectiveness while decreasing requirements associated with repair time, material and labor.

The Air Force **Aircraft Damage Effects Assessment program** is a project in partnership with NATO to improve aircraft survivability and vulnerability-assessment modeling techniques and to eliminate costly duplication of research and development efforts by collaborating on: development of a combined failure effects model; quantification of composite thermo-mechanical failure properties; assessment of hot surface ignition properties; assessment of aircraft skin-spar joint failure properties; and development of blast mitigation concepts and predictive models.

In civilian aviation, the FAA in May expanded its updated certification requirements to all general aviation pilots, including those trained by the U.S. military, to reflect more reliance on basic flying knowledge and skills and less on managing and observing the complex avionic instruments, as well as less preparing solely for scripted emergency scenarios. This expansion was due to the increased general aviation and airliner crashes attributable to pilot error. The added recertification training also includes recognizing stall condition and how to recover from it. All pilots must be retrained and recertified by March 2019, although in-flight training can start after that date. ★

Contributor: Jason A. Sawdy

▼ **The FAA** in May expanded its updated certification requirements to general aviation pilots. The requirements increase the focus on flying skills and knowledge over managing avionic instruments.



Interest grows in digital twins, digital engineering

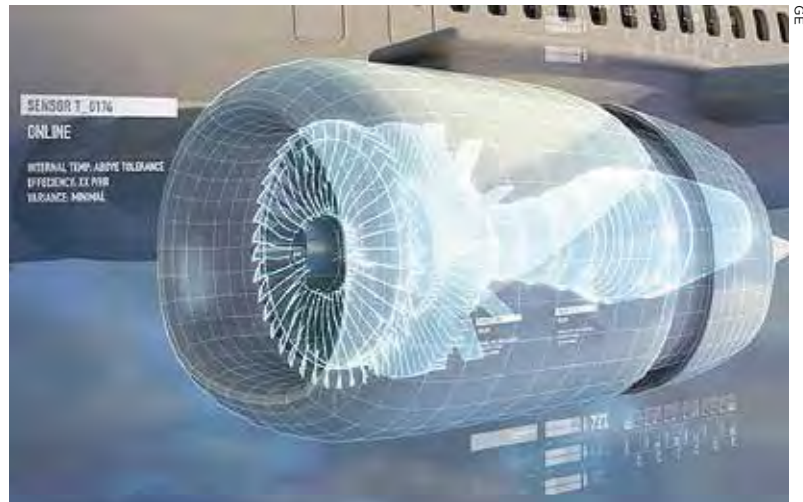
BY MICHAEL Z. MILLER AND
MARILEE J. WHEATON

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

Defense systems are characterized not only by their demanding missions, but also by the detailed documentation that must be created, managed and interpreted throughout a system's life cycle. The discipline of systems engineering was born out of these complex systems, with the goal of improving the success of these complex systems. However, the document-heavy approach of traditional systems engineering seems out of step with our modern age, which saw the emergence and primacy of computing, the internet and mobile technology.

One methodological solution to more manageable iterative development is **model-based systems engineering**, also called digital engineering, which was an emphasis area in 2017 for the Office of the Deputy Assistant Secretary of Defense for Systems Engineering, or ODASD(SE). With a model-based approach, the truth is resident in the model, not in documents. Systems models enable improved analysis of tradeoffs when considering a product's mission, requirement and design. Reviews can be conducted in a more effective and proactive manner. Documents may be generated as needed, but the accepted baseline is always in the integrated model, which the team creates, modifies and interprets during the evolution of the system design.

In September, the Systems Engineering Research Center, sponsored by ODASD(SE), began a research project to explore the effectiveness of digital engineering and systems engineering. In October, ODASD(SE) presented the **Digital Engineering Strategy and Toolkit** for use across the military service components. This was done at the National Defense Industry Association Modeling and Simulation Subcommittee meeting. The aim of digital engineering is "to help streamline the way defense programs collect, retain and share data. ODASD(SE) asserts that digital engineering has the potential to promote greater efficiency and coherence in defense programs by ensuring stakeholders



have access to accurate, relevant and consistent information throughout the life of a program," according to the ODASD(SE) website.

Digital engineering and model-based systems engineering can be further leveraged to produce **the concept of a digital twin for an engineered system**. A digital twin can be thought of as a digital model of a system that tracks the system throughout its life cycle. Any changes or updates that occur with the physical system are updated with its digital twin by adjusting the various models of that system. This enables engineers to perform more accurate analysis with a virtual replica of the real-world system.

The concept of the digital twin gained popularity in 2017 within aerospace engineering and in the education and training of future engineers. Some universities began exploring the idea of creating a virtual model, a spinoff from the digital twin concept, of each student to track the student's progress throughout his or her time at the university. It is believed that this would enable universities to not only perform better resource management, but also better understand the needs and interests of students outside the classroom. The virtual model concept is closely related to the growing interest in personalized education. In April, the New Profit venture philanthropy fund announced that the Chan Zuckerberg Initiative and the Bill and Melinda Gates Foundation will contribute **\$12 million over four years for the Personalized Learning Initiative**.

Furthermore, military applications of a digital twin to training could enable decision-makers to have a better understanding of war fighters' capabilities, previous training and skills. Ideally, this might enable a commander to more accurately select soldiers for given missions by querying the digital twins of soldiers to find desired attributes. ★

▲ **The concept of the digital twin** gained popularity in 2017 within aerospace engineering. Companies and educators create a digital model — in this case a model of an aircraft engine — to monitor and troubleshoot problems with the real engine.

Research targets quiet, efficient flight

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.

Jet noise reduction technologies for tactical aircraft saw continued refinement in 2017. In January, Embry Riddle Aeronautical University initiated a detailed computational analysis of the “fluidic inserts” concept developed at Pennsylvania State University. The concept enables operational control, allowing noise reduction to be activated during takeoff and deactivated in other flight regimes without a performance penalty.

Also in January, researchers at the University of Mississippi, University of Texas at Austin, and Combustion Research and Flow Technology Inc., or CRAFT Tech, of Pennsylvania began a **third-generation refinement of “contoured inserts.”** These shaped segments can be installed in the expansion section of a supersonic nozzle as a retrofit jet noise solution for tactical aircraft propulsion. These jet noise reduction activities represent a culmination of scientific refinement through years of detailed study by the academic community. In this regard, Dimitri Papamoschou, a professor at the University of California, Irvine, was awarded the 2017 Aeroacoustics Prize in recognition for his contributions to understanding jet noise generation mechanisms in supersonic jets leading to one of the most promising noise reduction methods in development.

In April, the **DGEN Aero-propulsion Research Turbofan**, or DART, was installed and operated at NASA Glenn Research Center’s Aero-Acoustic Propulsion Laboratory in Ohio. Researchers used the new system to complete a test of a 3-degree-of-freedom liner in August. DART, a fully mobile system for use in multiple facilities, uses a DGEN380 high-bypass geared turbofan engine produced by Price Induction. NASA engineers will use DART as a test bed to study and develop noise reduction and improved engine performance technologies.

Turning to unmanned air systems, in April, NASA’s Langley Research Center in Virginia completed **capability enhancements in the Low-Speed Aeroacoustic Wind Tunnel.** This enabled a study between April and August involving simultaneous measurement of aerodynamic performance and acoustics of small, electric

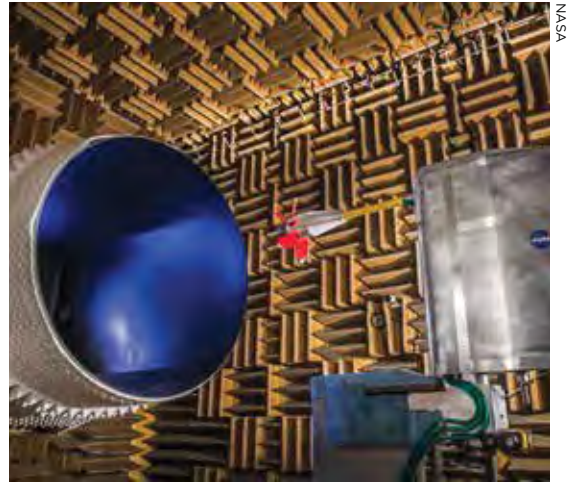
propeller and rotor systems applicable to small UAS. Also in April, researchers at the University of Texas at Austin measured the sound produced by multirotor drones during hover and demonstrated how the first and second rotor harmonics correspond to thickness noise and loading noise.

Researchers in the field of bio-inspired aeroacoustics presented results on **owl-inspired, low-noise airfoils** with applications ranging from small UAS to the largest wind turbine rotors. Specifically, in December 2016, the research team of Lehigh University, Virginia Tech, Florida Atlantic University and the University of Cambridge in Britain published findings on the reduction of roughness noise. In January, Iowa State University and Virginia Tech presented results on application-specific leading edge serrations, similar to those on owl wings, for the reduction of broadband propeller noise.

The Phased Array Benchmarking working group led by Langley concluded its third year with international engagement from industry, government and academic partners. Steady progress has produced a set of benchmark datasets useful for testing and comparison of various phased array data analysis approaches.

The **Kevlar-walled test section**, a concept Virginia Tech developed, this year saw application in a wider set of facilities. In February, Virginia Tech demonstrated the technique on a trailing edge noise test. Ballistic Kevlar cloth is used to separate the test section flow from an adjacent anechoic chamber where acoustic instrumentation is placed. These acoustically transparent walls eliminate the need for a collector, allow for a longer test section to better isolate the sound of interest, and greatly increase the quality and predictability of the flow. Several facilities are demonstrating this capability in their own facilities this year, including the 2-by-3-meter Danish National Wind Tunnel, the 1-by-1-meter wind tunnel at Beijing University of Aeronautics and Astronautics, and the Quiet Flow Facility at Langley. ★

Contributors: Clifford A. Brown, Dennis K. McLaughlin, Philip J. Morris, Tasos S. Lyrintzis, Nikolas S. Zawodny, Charles E. Tinney and William Deavenport



▲ A high-lift airfoil was tested this year in the Low Speed Aeroacoustics Wind Tunnel at NASA’s Langley Research Center in Virginia.

Improving measurement with spinning mirrors, schlieren images and magnetic suspension

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 a series of tests from January to March, MetroLaser of California demonstrated nearly instantaneous volumetric imaging of density in a turbulent jet using laser Rayleigh scattering. The technique is expected to enable detailed investigations of variable density flows that will advance the development of laser-based communications and weapons systems in which a light beam must propagate through a turbulent compressible flow field. Developed under U.S. Air Force funding, the method involves a rapidly spinning polygonal mirror that sweeps a pulsed laser sheet across the flow region of interest while a fast multiframe camera that is synchronized with the laser acquires images of Rayleigh-scattered light.

Instantaneous two-dimensional density distributions were produced in March, separated in time by 1.3 microseconds and in space by about 1 millimeter, forming a stack of images that comprise a three-dimensional rendering of the flow density. The density structure of a Mach 1.4 turbulent jet was analyzed, revealing flow features such as shock cells by essentially freezing them in time. Averaged volumetric density images were also obtained that offered more extensive coverage of the flow field. The knowledge of the instantaneous volumetric density field is critical for a priori determination of optical aberration that a laser beam suffers as it transits through such a flow field. MetroLaser in October was awarded a \$750,000 contract from the Air Force to develop the technique for larger instantaneous flow field coverage.

► **A model of a Mars** entry capsule, the object in the center of the image, was magnetically levitated this year in a series of experiments carried out by JAXA, the Japan Aerospace Exploration Agency. Red and blue light were shone on the model to measure its position.



JAXA

The HORIZON (High-Speed Original Research and Innovation Zone) research group at the University of Tennessee Space Institute continued research on the characterization of unsteady transitional shock wave/boundary layer interactions, or XSWBLI. The group has developed a robust post-processing algorithm to identify shock positions in large sets of high-speed schlieren images, and in April demonstrated that the technique compares favorably to similar measurements made with surface pressure sensors. Power spectra calculated from these high-speed schlieren images of XSWBLI have suggested that the unsteady shock motion may be caused by unsteadiness in the separated flow region just upstream of the shock generator. The group continued to refine a process for applying fast pressure-sensitive paint for the study of XSWBLI dynamics, following promising results of a demonstration as reported in a paper presented at the 2017 AIAA Aviation Forum. The work, sponsored by the Office of Naval Research, is ongoing and progress will be reported at upcoming conferences. HORIZON also made progress toward completing the new 24-by-24-inch TALon Mach 4 Ludwig Tube facility for a planned operational date before the end of 2017.

JAXA, the Japan Aerospace Exploration Agency, in February used a magnetic suspension balance system, or MSBS, to measure a dynamic stability derivative of a Viking-type Mars entry capsule. The MSBS eliminates interference due to physical model supports, which is much larger in such dynamic tests as the support also moves with the model. A ballistic range has been commonly used for the capsule in order to avoid the interference in spite of low reproducibility of the model motion. JAXA succeeded in achieving an uncertainty of 20 percent for the pitch stability derivative measurement by the MSBS, practically halving those of 33 to 300 percent in the past ballistic tests. This was accomplished by rotating the model 90 degrees axially and forcing pitch oscillation horizontally, enabling model motions to be precisely controlled without vertical movement of center of gravity and highly reproducible. ★

Contributors: Christopher Combs and Hiroki Sugiura
Thomas P. Jenkins is vice president of technology at MetroLaser.

David H. Plemmons is a senior scientist with the National Aerospace Alliance at the Arnold Engineering Development Complex.

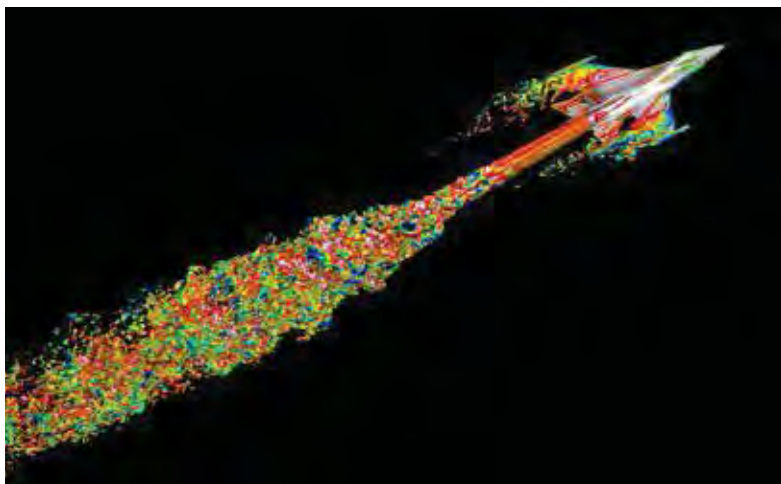
Christopher Combs is a research assistant professor in the HORIZON Group at the University of Tennessee Space Institute.

Hiroki Sugiura is an associate senior researcher at JAXA, the Japan Aerospace Exploration Agency.

Tech demonstration for future rotocraft

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.



Andrew Lohhouse/CREATE-AV Quality Assurance

The military and its aerospace industry partners made great strides in 2017 on advancing vertical flight.

The U.S. Army Aviation Development Directorate and industry partners flight tested two Joint Multi-Role Technology Demonstrator rotorcraft — the **Bell V280 Valor** air vehicle concept demonstrator and the **Sikorsky-Boeing SB>1 Defiant** — to demonstrate advanced technologies and prepare the Army for the Future Vertical Lift acquisition program. Army researchers worked with Bell, Sikorsky-Boeing, California-based Karem and South Carolina-based AVX to perform high-fidelity, high-performance computing physics-based modeling with the High Performance Computing Modernization's CREATE-AV Helios rotorcraft software to predict performance and better understand interactional aerodynamics. CREATE is short for the Computational Research and Engineering Acquisition Tools and Environments program. Results from the physics-based models are being compared with test data from both ground and flight tests as it becomes available to better understand the aircraft.

NASA's Advanced Air Transport Technology Project in January tested the **Fundamental Aerodynamic Subsonic Transonic-Modular Active Flow Control model** in the National Transonic Facility in Virginia. That model is based on a supercritical wing that was designed to become an NTF standard for evaluating performance characteristics of integrated active flow control

▲ **This is a high-fidelity physics-based CREATE-AV Kestrel simulation** of a maneuvering jet. Such simulations can predict the aerodynamic loading during difficult maneuvers. The colors in the wake of the aircraft are the vortical disturbances created due to aerodynamics and engine exhaust.

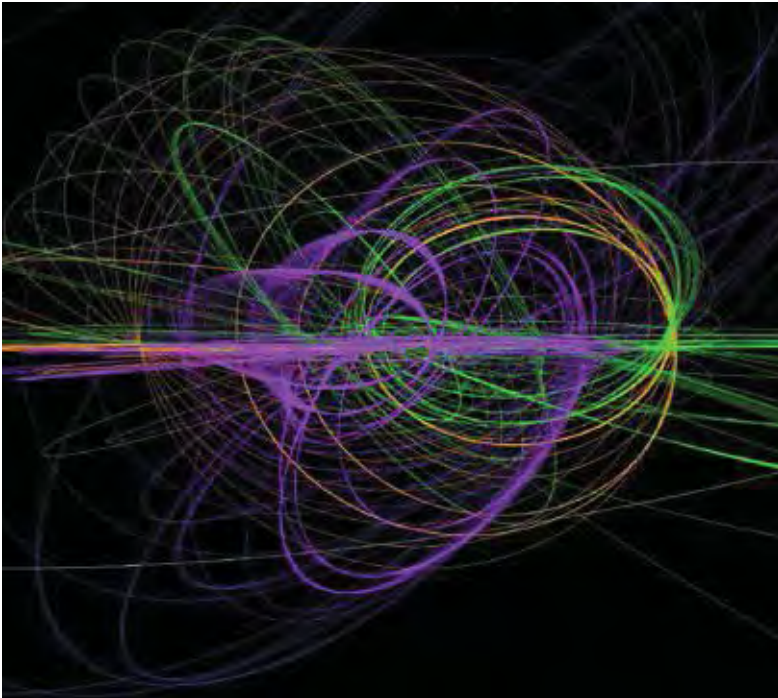
and propulsion systems. Arrays of sweeping jet actuators, fabricated using rapid prototyping, were located immediately upstream of the flap and used to control flow separation with the flap deflected and for cruise drag reduction with the undeflected flap. For the 30-degree flap subsonic, high-lift configuration, the sweeping jets achieved comparable lift performance in the separation control regime, while reducing the mass flow by 54 percent as compared with steady blowing. For the transonic cruise configuration, the sweeping jets reduced the drag by 3.3 percent at an off design condition.

The U.S. Army Aviation Development Directorate's Aeroflightdynamics Directorate has collaborated with NASA's Revolutionary Vertical Lift project office and Germany space organization DLR to **develop a way to measure time-accurate boundary layer transition locations** on a helicopter rotor blade in hover and forward flight. Forward flight testing began in June. Accurate transition measurements for a rotating blade have remained a challenge. Using recent advancements in long-wave infrared camera technology coupled with heatable coating on blade surface, boundary layer transition locations on a Mach-scale rotor were efficiently and accurately measured.

Transition location and hover performance measurement results were presented in January at the fourth AIAA Rotorcraft Hover Simulation session series at the AIAA SciTech Forum in Texas. The hover measurements and simulations discovered the amount of laminar flow present on model scale rotor blades in hover is significant and the amount of laminar flow has a considerable effect on hover performance.

The CREATE program continued developing and deploying scalable, multidisciplinary, physics-based computational engineering products for the design and analysis of ships, air vehicles and RF antennas. These products first became available in September; more were released through November. The Department of Defense released three products in 2017: the fixed-wing analysis tool Kestrel 8.0, the rotorcraft analysis tool Helios 8.0 and CREATE-AV Genesis.

Kestrel 8.0 introduces multispecies and supporting capabilities to bring together technologies for tackling hypersonic flow regime problems. Helios 8.0 introduces enhancements to automation and accuracy, including in turbulence and transition models. CREATE-AV Genesis is a combination of basic fluid dynamics and aircraft design software targeted toward teaching the next-generation of engineers at institutes of higher learning. It is being piloted at the school of Aerospace Engineering at Georgia Tech. ★



NASA

New missions and fiery end to Cassini

BY RYAN S. PARK

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

▲ All of **Cassini's orbits** — called a “ball of yarn” by NASA mission planners — are portrayed in this computer-generated image. The time represented is from Cassini's first orbit July 1, 2004, until the end of the mission on Sept. 15, 2017.

This has been a busy year for space exploration and astrodynamics with challenging milestones achieved and new frontiers opened.

The year started with NASA's January announcement of two new missions to study asteroids in the 2020s. The **Lucy mission** will study six Trojan asteroids captured by Jupiter and Sun's gravity, and the **Psyche mission** will study a unique metal asteroid known as 16 Psyche in the asteroid belt.

In March, SpaceX achieved the world's **first reflight of an orbital-class booster**; an important step to the commercialization of reusable launch vehicles. SpaceX's Falcon 9 rocket launched a geosynchronous communications satellite March 30. The first stage of this booster previously supported a space station cargo resupply launch for NASA in April 2016. Following stage separation, the same first stage returned to Earth for a second time, landing on a remotely controlled ship stationed in the Atlantic Ocean. This reflight represents a milestone on the road to full rocket reusability.

After 16 months of science operations, the European Space Agency's LISA Pathfinder com-

pleted its mission in June, demonstrating the drag-free technology necessary for ESA's future **Laser Interferometer Space Antenna** mission for detecting gravitational waves at low frequencies.

In July, U.S. Sen. Ted Cruz, R-Texas, chairman of the subcommittee on space, science and competitiveness, convened a hearing titled “Reopening the American Frontier: Promoting Partnerships Between Commercial Space and the U.S. Government to Advance Exploration and Settlement” for examining partnerships between the U.S. government and commercial space industry to advance space exploration. Fundamental problems in astrodynamics were reported at the hearing, with emphasis on current and predicted problems regarding orbital debris and space traffic.

On Sept. 1, a 4.5-kilometer asteroid named Florence, one of the largest of the near-Earth asteroids, made a close approach to Earth of nearly 18 lunar distances. Florence is the largest asteroid to pass this close to our planet since the first near-Earth asteroid was discovered over a century ago. Radar images of Florence obtained at the 70-meter antenna at NASA's Goldstone Deep Space Communications Complex in California revealed that the asteroid has two small moons. In March, it was announced that the same Goldstone radar had detected the Indian Space Research Organization's Chandryaan-1 spacecraft in orbit about the moon. Chandryaan-1 had not been tracked for eight years.

Beyond cislunar space, in February, managers for NASA's Juno spacecraft decided it would remain in a 53-day orbit — instead of the planned 14-day orbit — to avoid a potential risk of a main engine burn that could have resulted in a less-than-desirable orbit. NASA's Dawn spacecraft celebrated its 10-year anniversary in September. Dawn lost its third reaction wheel in April, leaving it fully reliant on hydrazine-based attitude control. Despite the operational challenge, Dawn remains in good condition, waiting for its next assignment. On Sept. 15, the **Cassini spacecraft** was intentionally plunged into Saturn's atmosphere, completing its “grand finale” phase 20 years since launch, with 13 years orbiting Saturn. This nuclear-powered spacecraft was one of the most ambitious space missions ever mounted as a joint endeavor of NASA, ESA and the Italian Space Agency.

ESA hosted the ninth **Global Trajectory Optimization Competition** in April. Thirty-six teams from around the world submitted solutions on how to actively remove a hypothetical set of space debris in orbit about Earth. The winning solution came from a team at NASA's Jet Propulsion Laboratory that solved the combinatorial orbital dynamics problem to remove all 123 orbiting debris pieces with 10 missions. ★

Understanding highly 3-D icing accretion

BY ANDY P. BROEREN, DALE C. FERGUSON AND PETER M. STRUK

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

Over the past several years, NASA has collaborated with the FAA and the French Aerospace Lab, ONERA, to investigate **in-flight icing on large-scale commercial transport airplanes**. A major program milestone was achieved in May with the completion of a large-scale, wind-tunnel campaign focused on understanding the aerodynamic effect of highly three-dimensional ice accretion.

The campaign's primary objective was to measure aerodynamic performance degradation due to artificial ice shapes on an 8.7 percent scale semispan, swept-wing model based on the NASA Common Research Model. The artificial ice shapes — designed in 2016 using the 3-D scan data of ice

► This 8.7 percent **scale NASA Common Research Model** semispan wing was tested in the ONERA F1 wind tunnel at Mauczac, France. An artificial ice shape (shown in white) was attached to the wing leading edge.



accretion measured during tests in 2015 — were completed in January. They were fabricated via rapid-prototype manufacturing and closely resembled the large-scale 3-D features of the ice accretion. Lower-fidelity artificial ice shapes without the large-scale 3-D features were also investigated.

The preliminary results indicate the large-scale 3-D features are significant with respect to the aerodynamic performance degradation associated with icing. The pressurization capability of the ONERA F1 wind tunnel was used to investigate changes in aerodynamic performance over Reynolds numbers from 1.6×10^6 to 12.0×10^6 and Mach numbers from 0.09 to 0.34. These changes were significant for the baseline, clean wing. For the wing with artificial ice shapes, the effects of

Reynolds and Mach numbers were significantly reduced. This work — the first of two planned test campaigns — will help evaluate the efficacy of 3-D icing-simulation tools.

In July, Glenn and the National Research Council of Canada conducted a test to study the **fundamentals of ice-crystal ice accretion**. The testing at the NRC Research Altitude Test Facility in Ottawa, Ontario, sought to generate icing conditions representative of those that occur inside a jet engine when ingesting ice crystals. An airfoil was exposed to those conditions, and the resulting ice accretions were recorded. This data will help extend predictive ice-accretion codes to include conditions occurring in engine icing.

Turning to space environments, scientists analyzed data of solar array arcing aboard two GPS satellites and one Van Allen Probe satellite; a preliminary analysis was published in May in AIAA's *Journal of Spacecraft and Rockets*. A team comprised of members from the U.S. Air Force Research Lab, Los Alamos National Laboratory and Assurance Technology Corp. captured the data in 2015 and 2016 with the radio telescope at the Arecibo Observatory in Puerto Rico. After eliminating narrowband interference, broadband total power was sampled at 9.6 or 19.2 microseconds per sample. The evidence for arcing is in breakpoints of autocorrelation functions of the total power signal centered at 327 and 430 megahertz, which were not present in off-source scans. The breakpoints indicated widths of 60-160 microseconds, timescales not common in broadband interference but representative of arc plasma flashover.

The possibility of detecting satellite arcing at radio frequencies was predicted in papers from 2014 to 2016. The frequency of occurrence of the observed GPS arcing is similar to the undispersed event rate seen by the Los Alamos' U.S. Nuclear Detonation Detection System radio-frequency detectors on GPS satellites, which is highly correlated with the surface charging electron flux variations in GPS orbits as predicted by the AE9/AP9/SPM empirical magnetosphere model. The arc strength and frequency of occurrence are enough to completely account for the measured power degradation in excess of radiation damage, if the source of the excess degradation is arc-induced contamination of the GPS solar arrays. AFRL Spacecraft Charging and Instrument Calibration Laboratory arcing data on a small GPS array sample constructed and I-V tested by AFRL shows power loss consistent with the hypothesis. The frequency of arc occurrence is much greater than commonly assumed. Mitigation may prevent future excess power degradation and may make possible downsizing future GPS arrays by 20 percent with no loss of end-of-life power. ★



◀ Sierra Nevada's Dream Chaser is lifted off a ramp at NASA Armstrong by a Chinook helicopter for a captive carry flight.

at which it was expected to free fly later in 2017.

The Dream Chaser is meant to carry cargo to and from the International Space Station. NASA says it will fly at least six resupply missions to and from the space station beginning in 2019.

The captive carry test was an important milestone in the vehicle's development. A second captive carry test was planned for later in 2017. After the test, the vehicle was to undergo free-flight testing via helicopter drops to test its final approach and landing sequence. The Dream Chaser also completed a series of ground tests in 2017.

Pilots began flying a flight simulator for the **X-57 Maxwell aircraft**, which was revealed at AIAA's 2016 Aviation Forum and Exposition. The X-57 is a modified Tecnam P2006T aircraft intended to reduce fuel consumption, emissions and noise through an array of 14 propellers driven by electric motors. The simulator is meant to familiarize pilots with the all-electric vehicle. Mod II of the X-57 is under construction at Armstrong and will begin flight testing next year.

A team of academic and industry researchers with NASA's **Performance Adaptive Aeroelastic Wing project** flight-tested three controllers for active flutter suppression on their flying-wing research drone. All operated as designed, and two flew above the flutter speed. The University of Minnesota leads the team, which is also comprised of Virginia Tech, Systems Technology Inc., D.K. Schmidt and Associates, CMSoft Inc. and Aurora Flight Sciences.

NASA

Working under the sponsorship of the Center for Unmanned Aircraft Systems — a National Science Foundation Industry-University Cooperative Research Center — researchers with Brigham Young University and Virginia Tech established the **Small Aircraft Flight Encounters Database** to share data collected to support see-and-avoid algorithm development. Initial data sets containing visual and radar imagery, position and attitude histories, and more from NASA, the National Research Council and a BYU/Virginia Tech flight campaign are available. The team is also welcoming additional data contributions.

In July, the **German Aerospace Center's SAGITTA drone** completed its first flight test. The experimental vehicle has a lightweight all-composite airframe and is designed as a testbed for autonomous vehicle systems. The drone thus far has made significant advancements in ultra-light structures, electro-mechanical actuators and landing gear systems. ★

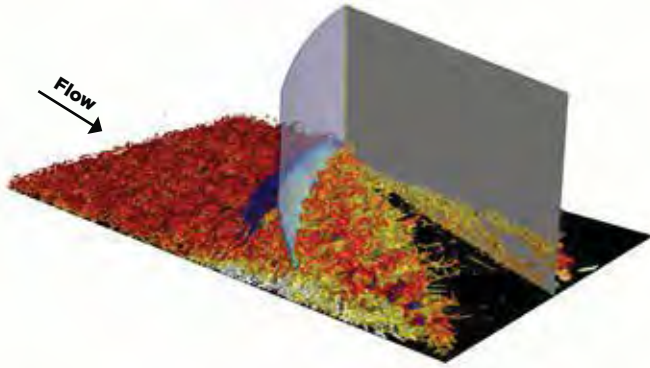
Dream Chaser completes a captive carry

BY CHRIS KARLGAARD AND CRAIG WOOLSEY

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

The year saw many advancements in the area of autonomy in aeronautics, including development of space vehicles and unmanned aerial systems. Many flight tests were conducted around the world to advance these technologies.

Sierra Nevada Corp. completed a **captive carry test of its Dream Chaser** spacecraft Aug. 30 at NASA's Armstrong Flight Research Center in California. A Chinook helicopter carried the Dream Chaser to the same altitude and flight conditions



Focus on ability to predict separated flow

BY TIM EYMANN

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.

▲ **Large eddy simulations of the flow field** around a sharp fin at Mach 2. The image shows velocity contours (colors represent different velocity magnitudes) before and after the shock boundary layer interactions. Air flow is from left to right.

The study of separated flow and improving the ability to numerically predict it was a major topic of interest for fluid dynamics researchers in 2017. Researchers at NASA's Langley Research Center in November conducted the NASA Juncture Flow in the 14-by-22-foot (4.3-by-6.7-meter) subsonic tunnel and planned to continue through December. The wind tunnel tests are designed to provide validation-quality data for the onset and progression of a trailing edge separation near the wing-body juncture of an aircraft. This type of separation is particularly difficult for state-of-the-art computational fluid dynamics, or CFD, methods to predict.

Separated flow is a dynamic physical phenomenon that can adversely impact the performance of aerospace vehicles. The mechanisms that lead to and result from separated flow make it difficult to model its effects with the current generation of production CFD software.

The **NASA Juncture Flow experiment** is providing highly detailed information that can improve the accuracy of the current numerical methods. A unique aspect of the tests is that a laser Doppler velocimetry system is mounted inside the fuselage, taking measurements through windows to capture high-resolution flow data close to the corner region. The tests are the culmination of a significant body of preparation work, including several risk-reduction experiments that identified optimal wing configurations for achieving the desired corner flow separation characteristics.

An additional class of separated flow, smooth-body flow separation, occurs when a boundary layer attached to a solid surface separates after interacting with an adverse pressure gradient generated by a change in the body contour or the presence of a shock. Simulations that rely on the Reynolds-averaged Navier-Stokes equations to

simulate the turbulent flow have difficulty predicting the onset and evolution of separated flow and therefore misrepresent its effects on a vehicle.

Scientists at Langley are taking a higher-fidelity approach to modeling the turbulence known as wall-resolved large eddy simulations. The researchers combined this turbulence modeling approach with high-order numerics to simulate a canonical test problem on supercomputers at the Department of Energy using up to 24 billion grid points, which is over 200 times larger than a typical CFD run. From April to October, their work demonstrated that the power of the top supercomputers makes it feasible to **perform turbulence simulations at physically relevant conditions**. The data generated from these simulations are giving scientists a better understanding of flow separation physics.

At faster speed regimes well above the speed of sound, shock wave-turbulent boundary layer interactions are ubiquitous, occurring along both external and internal flow paths. This high-speed flow phenomena can not only induce flow separation, but also vortical structure formation and pressure losses, as well as amplify heat transfer, all of which can be detrimental to the vehicle operation. While researchers have characterized the physical drivers behind two-dimensional interactions, more realistic three-dimensional interactions have not been studied as extensively. Researchers at Florida State University, Ohio State University, the University of Texas at Austin and Auburn University are working jointly on an Air Force Office of Scientific Research project to **fully understand three-dimensional shock/turbulent boundary layer interactions**.

Throughout the year, researchers at the partner universities have made measurements on a fin-on-plate and a swept corner configuration using high-fidelity diagnostics. One such test occurred in June at the Florida Center for Advanced Aero-Propulsion Supersonic Wind Tunnel Facility at FSU. The experimenters and CFD researchers are also using outputs generated from small-perturbation inputs to feed large eddy simulations intended to cast regions of the flow as a dynamical system and to numerically study the underlying mechanisms that result in the experimentally observed unsteadiness. The work has revealed the features of the separated flow with remarkable clarity and highlighted the differences between two- and three-dimensional physics. The outcome of this combined experimental and computational research effort will help guide the design of next-generation high-speed flight vehicles. ★

Contributors: Rajan Kumar, Mujeeb Malik, Christopher Rumsey and Ali Uzun

Public, private sector improve wind tunnels

BY RYAN KEW

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

Ground testing in 2017 was full of wind tunnel upgrades, calibrations and a return to supersonic aircraft design. Lockheed Martin, in partnership with General Motors, completed a six-month, \$12 million renovation of Lockheed Martin's Low Speed Wind Tunnel in Marietta, Georgia. The renovations replaced the 1960s-era marine plywood tunnel walls with modern perforated stainless steel panels and two sets of acoustically dampened turning vanes. The new walls and vanes in the 16-by-23-foot (4.8-by-7-meter) test section provide a quieter environment. The overall sound pressure levels were predicted to go down by 13.6 decibels (acoustic) — 81.8 dbA at 70 mph reduced to 68.2 dbA. However, the improvement appears to be larger. Data is still being analyzed.

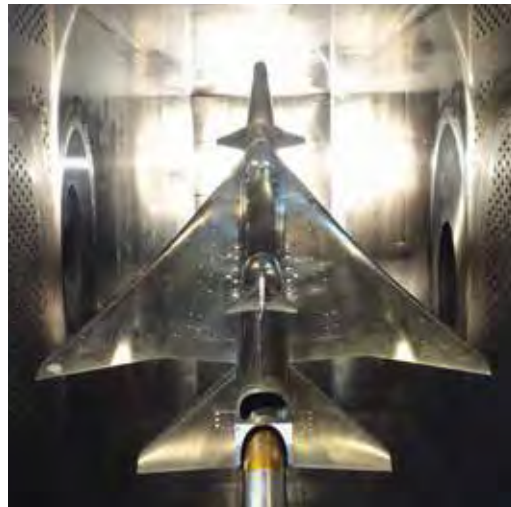
"We have been told that we now have the quietest closed test section wind tunnel in the world," said Joe Patrick, wind tunnel director. "As we start our sixth decade of testing, we essentially have a brand new wind tunnel."

Internationally, the 22.5 megawatt main drive motor in the **Japan Aerospace Exploration Agency's 2-by-2-meter transonic wind tunnel** was first tested in May. The final shakedown test of the wind tunnel was conducted in September. The motor had been removed in June 2016 and replaced in October 2016. The wind tunnel was built in 1960. This was the motor's second replacement; the first was in 1987. The length of the new motor requires less space and the motor weighs less at 100 tons. Four parallel inverter drives with an insulated-gate bipolar transistor power the motor. The wind tunnel update also included new controls. Originally, JAXA employees operated the tunnels' five major components. The upgraded tunnel is more efficient, and a single operator can fully control it.

Northrop Grumman Corp. contracted Calspan's Force Measurement Systems, or FMS, to support the **recalibration of a load cell array to measure the aerodynamic forces** on a test assembly at the National Full-Scale Aerodynamics Complex at NASA's Ames Research Center at Moffett Field, California. FMS designed hardware to

supplement the loadings, expanding the number of possible load combinations and more closely mimic the testing environment of the wind tunnel. The six-load cell array was manually calibrated over two weeks at the end of March, resulting in a three-force, three-moment multicomponent balance characterization of the system, providing increased accuracy beyond the original equipment manufacturer calibration.

NASA's Langley Research Center in Virginia developed and refined calibration techniques with continued work on the design of new calibration hardware. The In Situ Load System, or ILS, provided multicomponent check loads to a rotorcraft model to alleviate concerns regarding the performance of a force balance used for the rotor system loads. Several sets of check loads were conducted in 2017 to verify the balance performance while considering the full model system. This demon-



◀ **The preliminary design** of Lockheed Martin's Quiet Supersonic Technology X-Plane undergoes high-speed testing in the 8-by-6-foot supersonic wind tunnel NASA's Glenn Research Center in Ohio. NASA

stration was the first time the ILS was integrated into a production test model and will help merge the concept into other facilities.

Supersonic passenger airplanes are another step closer to re-emerging. In May, NASA's Glenn Research Center in Ohio completed the first high-speed wind tunnel tests on the preliminary design of Lockheed Martin's **Quiet Supersonic Technology X-Plane, or QueSST**. Testing ranged from Mach 0.25 to Mach 1.6, leading an effort to separate the shocks and expansions associated with supersonic flight to dramatically reduce the aircraft's loudness on the ground. The QueSST design is one of a series of X-planes envisioned in NASA's New Aviation Horizons initiative, which aims to reduce fuel use, emissions and noise through innovations in aircraft design. ★

Editor's note: Ryan Kew works for Calspan.

Contributor: James Sizemore

Drone registration, reusing first stages

BY UDAY J. SHANKAR, LESLEY A. WEITZ AND JOHN G. REED

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



Lone Star UAS Center

▲ **Lone Star UAS Center** at Texas A&M Corpus Christi flew drones over areas affected by Hurricane Harvey to help local officials spot damage.

The guidance, navigation and control field had an eventful year, covering all aspects of aerospace engineering.

In August and September, unmanned aerial systems recorded images of the damage and the state of infrastructure in Texas in the **aftermath of Hurricane Harvey**. The Texas A&M University, Corpus Christi, drone team worked with local authorities and with the FAA's permission to fly UAS over areas affected by the hurricane. Privately owned drones pose risks to military and civilian assets during rescue efforts when users violate FAA-issued temporary flight restrictions. Since June 2016, all small-drone users had been required to register their UAS. However, that changed in May when a **federal court ruled some hobbyists didn't need to register their drones**.

In January, NASA signed an agreement to **transition UAS Traffic Management research to the FAA** in 2020. NASA has been working on the UTM concept since 2014.

The past year has also been eventful for launch vehicles. The guidance, navigation and control systems on SpaceX vehicles enabled the

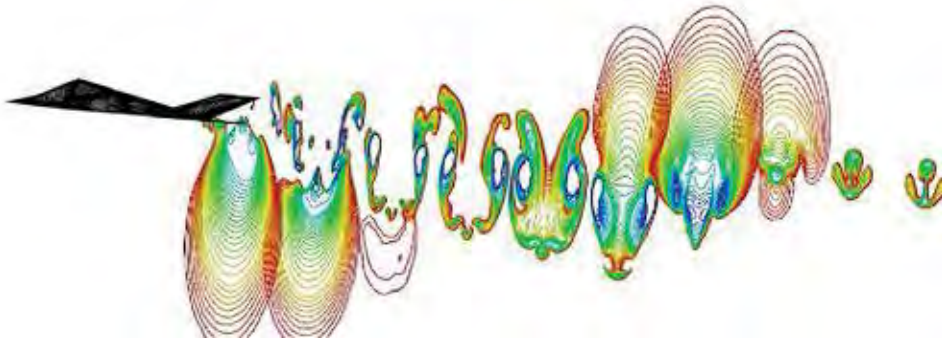
reuse of a Falcon 9 booster in March and a Dragon spacecraft in June — firsts for both systems. SpaceX also reused Falcon 9 boosters in June and October. On the small launch vehicle side, California-based Rocket Labs demonstrated its low-cost guidance, navigation and control systems with its Electron launch vehicle's flight to space in May. Those systems performed nominally, until a ground system fault resulted in flight termination. In June, India launched its Geosynchronous Launch Vehicle Mark III rocket, capable of taking 4 tons to geostationary transfer orbit. On the heavy side, in March, Blue Origin announced the development of its reusable New Glenn rocket.

Development of next-generation systems continued worldwide. United Launch Alliance tweeted about progress on the Vulcan rocket. The European Space Agency in July reported progress toward a requirements review in 2018 for the Ariane 6 rocket. The U.S. military awarded Boeing a contract in May for its **Phantom Express spaceplane**. And in September, Elon Musk gave an update on SpaceX's Interplanetary Transport System design at the International Astronautical Federation.

Several systems met milestones in 2017. The Interim Cryogenic Propulsion Stage for NASA's Space Launch System was delivered to NASA's Space Station Processing Facility at the Kennedy Space Center in July. Lockheed Martin powered up the Orion spacecraft for the first time Aug. 22 at Kennedy.

An era ended as Russia retired the Soyuz-U launch vehicle in February after more than 785 missions. On Sept. 15, NASA's Cassini plunged into Saturn's atmosphere, with the guidance, navigation and control system keeping the antenna pointed toward Earth. Launched 20 years ago, Cassini had orbited Saturn more than 290 times.

Finally, NASA's Langley Research Center celebrated its 100th anniversary July 17. Langley has long been at the forefront of aircraft control systems, and the U.S. space program was born there. Stabilization, guidance and control systems considerations led to the now-famous shuttlecock-shaped design for the first U.S. space capsules. Early concepts for the space shuttle were designed and tested at Langley. The center is also home to NASA's Engineering and Safety Center, which investigates engineering aspects of all aerospace failures. In September, **Langley opened the Katherine G. Johnson Computational Research Facility**, named in honor of the black female mathematician who, among other accomplishments, calculated astronaut Alan Shepard's flight trajectory in 1961. She was also one of the subjects of the book and film "Hidden Figures." ★



Meshing, visualization tests show promise

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.

▲ **This CFD simulation** couples moving mesh methods and adaptive meshing. It shows vortical flow prediction of a nosing-up notional F-117 aircraft using dynamic anisotropic mesh adaptation simulated using the Wolf flow solver.

Frédéric Alauzet

One of the first higher-order finite-element full aircraft simulations was presented in June at the 1st AIAA Geometry and Mesh Generation Workshop, where members of industry, academia and government from several technical committees and multiple countries came together to advance goals and address concerns laid out in NASA's CFD Vision 2030 Study. New techniques in mesh adaptation were also showcased and significant progress was made in higher order mesh generation. In addition to providing a datum against which future progress in geometry modeling and mesh generation can be measured, the workshop provided a model for sharing results and best practices within the computational fluid dynamics community that will continue into the future.

Supported by grants from the U.S. Department of Energy Office of Advanced Scientific Computing Research, Intelligent Light completed work toward developing CFD methods to meet the CFD 2030 vision in December. Among these were **new methods for visualizing high order results and curved grids** and a web-based uncertainty quantification framework that allows users to create two-dimensional plots and three-dimensional visualizations of CFD solutions and manage and explore associated uncertainty.

Pointwise completed a Commercialization Readiness Pilot contract in August for the U.S. Air Force to develop an integrated overset meshing and grid assembly capability. Software was provided to the Air Force that included capabilities

such as improved meshing and remediation, hierarchical frameworks, examine enhancements and mesh assembly integration. Part of the improved meshing capability was a mesh smoothing method for the viscous layer prism extrusion process. The formulation and examples that first demonstrated this capability were presented in the paper "**Optimization-Based Smoothing for**

Extruded Meshes," which was this year's recipient of the Meshing, Visualization and Computational Environments Shahyar Pirzadeh Best Paper Award.

Mesh adaptation and smoothing, where the clustering and point-density of the computational mesh is driven by the physics of the flow field or geometric considerations, continues to be a topic of considerable interest. New adaptation techniques, developed by Inria (The French National Institute for Research in Computer Science and Control) and Boeing, were shown to improve CFD results. These techniques impacted solutions at several validation workshops including Sonic Boom Prediction in January and High Lift Prediction in June.

Use of in-situ data processing, in which data is intelligently reduced, analyzed, transformed and indexed while still in memory before being written to disk or transferred over networks, continues to expand. A tool that gained traction this year was the **open source visualization tool VisIt**, along with Libsim, an associated library used to instrument simulations for in-situ visualization. These tools were leveraged to enable JAXA, the Japan Aerospace Exploration Agency, to instrument its CFD solver to study launch vehicle acoustics and the University of Wyoming to instrument its high order computational framework to analyze a 1 billion degree-of-freedom wind turbine farm simulation.

A core part of the CFD process is the computational environment in which the simulation takes place. While computational environments are not as easy to define as meshing and visualization, an important aspect is the framework that initializes, executes and manages the various tasks in the process. One of the quickest growing frameworks, both in terms of user penetration with 500-plus active licenses and in terms of capability, is Kestrel, which saw several updates in 2017, including simplified boundary condition handling and the incorporation of a new visualization manager. These new capabilities directly assisted CREATE (Computational Research and Engineering Acquisition Tools and Environments) in its mission to improve the Department of Defense acquisition process. ★

Training pilots to avoid, react to stalls

BY JEFFERY A. SCHROEDER

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.

The commercial transport airplane community will soon comply with a requirement to train all of its pilots on upset prevention and recovery. In the U.S., this requires training airline pilots to prevent full aerodynamic stalls or, if not prevented, to recover from such a stall. All of this training will be performed in a flight simulator. Aircraft manufacturers and engineering consulting firms are developing improved aerodynamic models to enable the stall and upset training, and as of September, the FAA had approved approximately 40 upgraded flight simulators to meet the training requirements.

In September, the University of Toronto, with subcontractor Bombardier, completed a transfer-of-training simulation study in Toronto on a turboprop aircraft model. The study examined how upgraded stall aerodynamics — developed using a combination of engineering judgment, certification flight test data and existing static wind-tunnel data — might influence stall training.

Several high-fidelity simulators are being used to examine **possible simplified criteria for commercial transport go-arounds**. While criteria currently exist for stabilized approaches, a Flight Safety Foundation study originally published in 2012 showed that crews conduct a go-around only about 3 percent of the time these criteria are exceeded. Fewer, but key, criteria were to be examined in Oklahoma City in

▼ **This is the view** of a possible go-around condition in a 747-400 simulator study.



NASA

October with the decision altitude being lowered to hopefully reflect actual decision-making by today's crews.

A final study on objective flight simulator motion cueing criteria was completed in February on the NASA Ames Vertical Motion Simulator at Moffett Field near Palo Alto, California. New simulators in the U.S. must now objectively measure their motion responses using the Objective Motion Cueing Test, first published in 2009 by the International Civil Aviation Organization. To date, while solid measurement techniques are being used, consensus criteria to assess the measurements are lacking. Results from this final study will propose criteria.

In June, flight simulation experts gathered at the Royal Aeronautical Society in London and agreed on a list of seven flight simulator problems that need further attention. These are: better aligning simulator qualification procedures with training objectives; reducing flight test hours significantly via simulation; creating consensus objective motion standards; developing a cost-effective and widely accessible rotorcraft simulator; finding good objective measures for training effectiveness; seamless sharing of scenarios across simulator environments; and making simulated turbulence feel more like real aircraft turbulence.

Throughout 2017, **model-based development and model-based system engineering** industry trends continued. These concepts are slowly gaining acceptance as a way to reduce aerospace product development costs by enabling early requirements validation and systems integration long before any real hardware is built. These models are also being used as single-source-of-truth models to enable lossless knowledge transfer across engineering domains and lifecycle phases.

At Moffett Field in June, NASA developed the basic framework for simulations to evaluate technologies for **integrating unmanned aircraft into the national airspace**. The goal is to develop a relevant test environment for validating human systems integration guidelines, sense and avoid, and command and control standards.

In military applications, at the Society of Experimental Test Pilots Annual Symposium in September, the U.S. Navy made a presentation on its use of a Calspan Learjet in-flight simulator at Niagara Falls Airport in New York to test the feasibility of a landing signal officer on the ground remotely piloting the landing of an unmanned aerial vehicle with degraded automatic landing system or of piloted vehicles with fatigued pilots or rough seas. The concept was favorably demonstrated nearly to touchdown with just under 100 passes over eight flights. ★

Advances in ultra-short laser pulse technology

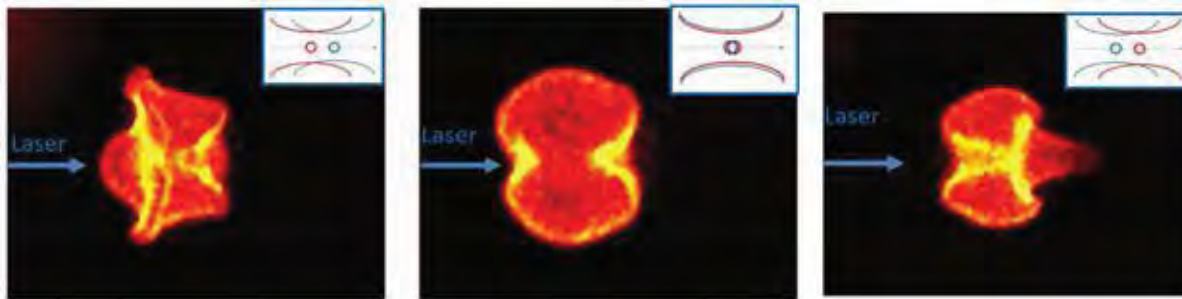
BY MICHAEL D. WHITE, DAVID L. CARROLL AND JOSEPH W. ZIMMERMAN

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

Researchers at the University of Oxford reported in July the first experimental demonstration of a multipulse laser wakefield acceleration with a structure that is long compared to the plasma period and avoids the relativistic saturation that occurs with the similar plasma beat-wave accelerators. They found that if the pulses are separated by the wavelength associated with the natural radiating frequency of the plasma, then the pulses add coherently, resulting in an amplitude growth at the back of the pulse train. This technology could

studies. Experiments combining acoustics measurements and proper orthogonal decomposition analyses of hydroxide fluorescence revealed the impact of microwave energy on the flame behavior. A 43 percent decrease in fuel-to-air limit was shown with microwave power deposition around 60 watts — less than 5 percent of the combustion power. Heat-release fluctuations were significantly reduced, establishing improved mean energy content up to 23 percent; root-mean-square pressure fluctuations were reduced by up to 47 percent.

Another UIUC-CUA team demonstrated an innovative **plasma flow control actuator that produces a high-voltage plasma arc positioned within the field of a strong ring magnet**. Similar in concept to microwave-generating cyclotrons, the cyclotronic plasma actuator serves as a controllable vortex generator that can be enabled or disabled on demand in boundary layer flows when the coaxial arrangement is embedded in an aerodynamic surface, thereby alleviating turbulent flow separation (e.g., during takeoff and landing). It also does not produce parasitic drag during high-speed cruise. Compared to traditional dielectric



lead to very compact, efficient plasma particle accelerators potentially operating at pulse rates significantly higher than existing ones.

In another development of ultra-short laser pulse technology, researchers at Colorado State University reported in August having developed a novel laser ignition technique using the short pulses at different wavelengths separated by 15 nanoseconds. The first ultraviolet pulse at 266 nanometers generates a pre-ionized region. This is followed by a near-infrared pulse at 1,064 nm, resulting in the pre-ionized seed electrons generating an electron avalanche process. The resulting technique allows for decreased laser energy requirements while increasing combustion efficiency.

Researchers at the University of Illinois at Urbana-Champaign, or UIUC, and with Champaign-based CU Aerospace, or CUA, in early 2017 wrapped up work on **microwave plasma-assisted combustion in methane-air mixtures at atmospheric pressure**, merging advanced optical diagnostics techniques and multiphysics simulation

barrier discharge actuators, the cyclotronic plasma actuator may add more energy into the plasma, improving actuator authority and effectiveness.

Researchers at Xi'an Jiaotong University in China demonstrated **the ability to control the interaction between a supersonic shock wave and boundary layer by introducing an array of plasma actuators**. A fraction of a millisecond after activation, the researchers demonstrated a significantly weakened shock wave and reduced unsteadiness in a ramp configuration.

The researchers behind an international collaboration between the Electrofluidsystems Ingenieurbüro Göksel in Berlin and St. Petersburg State University in Russia in April published information they presented in 2016 on how they adapted a design originally meant for fusion to create a breakthrough magneto-plasma propulsion system. The design works at 1 atmosphere and could have a thrust-to-area ratio competitive with modern jet engines when driven at a kilohertz pulse rate. ★

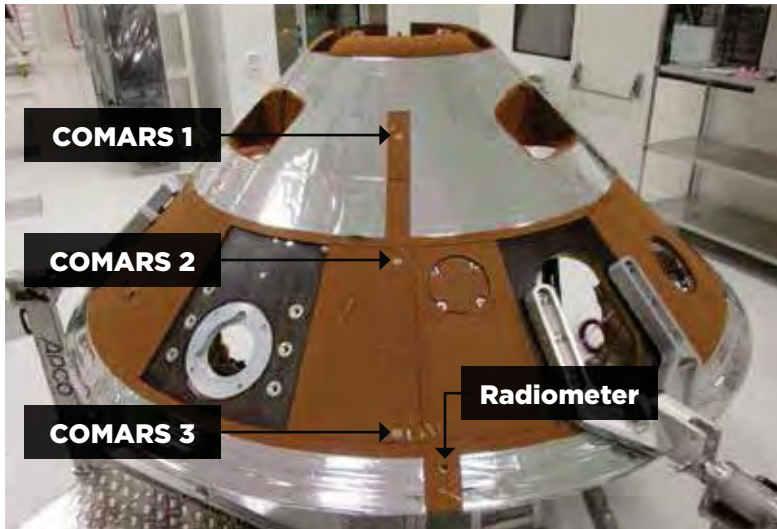
▲ **Dynamics of a flame kernel** based on the spatial overlap between two ultra-short laser pulses. These images were taken with a delay of 1 millisecond with respect to the laser firing. Inserts at the top right corner show the spatial overlap of the ultraviolet (blue) and near-infrared (red) beam waists. (The beams in the middle insert are laterally offset for visual clarity.)

Colorado State University

Validating advanced thermophysics models

BY AARON BRANDIS AND ROSS CHAUDHRY

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



In 2017, the thermophysics community obtained aerothermal flight data at Mars, improved the ability to use fundamental chemistry data in design tools, and investigated meteor entry in high-enthalpy experimental facilities.

Researchers from the European Space Agency's **ExoMars mission** in June presented flight data from the Schiaparelli module's entry into the Martian atmosphere. The data obtained during Schiaparelli's descent will be invaluable for validating models used to design thermal protection systems for future Mars missions. Reliable flight data is essential for the optimization of heat shield design, which in general is carried out with relatively high safety margins. High margins compensate for the large uncertainties associated with simulation tools when used to predict aerothermal loads on a spacecraft. For example, consider the radiative heating that is created by hot carbon dioxide molecules in the flow around the back-shell. This heating mechanism has not been accounted for in most previous Mars mission designs. Therefore, DLR, the German Aerospace Center, developed the **Combined Aerothermal and Radiation Sensor package, called COMARS+**, to measure the aerothermal and radiative loads at different backshell positions on Schiaparelli. COMARS+ consisted of three combined aerothermal sensors, one broadband radiometer sensor and an electronic box. Because Schiaparelli crashed on the Mars surface, DLR could not retrieve the complete data package. However, communications between

▲ **The Combined Aerothermal and Radiation Sensor package on COMARS+** was installed on the back cover of Europe's Schiaparelli spacecraft to measure the aerothermal and radiative loads at different backshell positions during the Mars descent.

the Schiaparelli module and the orbiter during entry allowed data to be transmitted at 10 trajectory points. Ongoing post-flight analysis, including tests in the arc jet facility L2K at DLR Cologne, are providing unique data for future Martian missions.

Computational chemists at the University of Minnesota in July and October published potential energy surfaces, or PESs, for $O_2 + O_2$ and $O_2 + O$ interactions relevant to conditions representative of hypersonic speeds. PESs are high-quality fits of the atomic forces that exist during molecular collisions and are used to investigate the dynamics of a dissociating gas, which are often in thermal non-equilibrium. These investigations lead to an improved understanding of reaction rates implemented in computational fluid dynamic simulations. Researchers in aerospace departments at the University of Illinois at Urbana-Champaign and the University of Minnesota use PESs with two different methods to predict non-equilibrium internal energy distributions. In a collaboration presented at AIAA's 2017 Aviation/Thermophysics Conference, these two methods were demonstrated to be consistent for the case of nitrogen dissociation. PESs are now available for many important reactions relevant to Earth entry, and by correctly modeling non-equilibrium and its effect on chemical kinetics, this work is expected to lower uncertainty margins and enable novel vehicle design.

Thermophysics research groups this year leveraged high-enthalpy experimental facilities traditionally used for testing spacecraft thermal protection system materials to study the complex phenomena of a meteor entering Earth's atmosphere. **Researchers in Japan studied synthetic meteorites in an arc heated wind tunnel** in preparation for a planned artificial meteor shower at the 2020 Olympic Games. Groups in Europe, at the von Karman Institute and the University of Stuttgart, used plasma wind tunnel facilities, including the Plasmatron and PWK1 respectively, to study emission spectra from meteorite samples. At NASA's Ames Research Center in California, meteoroid ablation was studied in detail in the Interaction Heating Facility in July to aid in developing models for asteroid threat assessment. The data from all of these experiments are being used to advance state-of-the-art numerical modeling of meteor entries.

By obtaining aerothermal heating flight data at Mars, understanding how to efficiently use elaborate quantum chemistry data in production design tools, and investigating the physics of meteor entry in high-enthalpy ground tests, the ability to validate complex thermophysics models is greatly improved. ★

Contributors: Ali Guelhan and Eric Stern

Novel aircraft are being safely integrated into airspace

BY DAVID THIPPHAVONG AND ARWA AWEISS

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

According to the International Air Transport Association, global airline industry profits are projected to dip slightly to \$31.4 billion in 2017 from \$34.8 billion in 2016. In North America, a net post-tax profit of \$15.4 billion is expected in 2017, with a net post-tax profit margin exceeding 7 percent. This strong economic performance was attributed to the consolidation of commercial airlines, which has helped to maintain high passenger loads.

In the United States, Congress has been exploring the transfer of air traffic control from the FAA to a private nonprofit corporation as it is in about 60 other countries, including Canada, Australia and Germany. In June, the chairman of the U.S. House Committee on Transportation and Infrastructure, Rep. Bill Shuster of Pennsylvania, introduced House Resolution 2997 or “The 21st Century Aviation Innovation, Reform, and Reauthorization Act” to privatize air traffic control. Supporters include the White House, the National Air Traffic Controllers Association and all major airlines, which argue that doing so would stabilize the funding stream needed to modernize the nation’s air transportation system. Opponents include small airports and general aviation, which contend that doing so would favor the major airlines and busy airports at the expense of rural communities. In July, the Senate advanced an FAA reauthorization bill that does not include the transfer of air traffic control to the private sector. As of October, the House of Representatives had yet to vote on the measure.

In the meantime, an ongoing effort conducted under **NASA’s Airspace Technology Demonstration-2** project is aimed at improving operational predictability in addition to efficiency. In collaboration with the FAA and industry partners, ATD-2 combines NASA-developed trajectory prediction and scheduling technologies with current and near-term FAA decision support systems to integrate arrival, departure and surface operations. ATD-2 is being developed and demonstrated in multiple phases through 2020. Phase 1 is focused on time-based departure scheduling and data exchange for minimizing surface congestion and enabling flights



NUAIR Alliance

to smoothly merge into busy overhead streams. The Phase 1 demonstration began at Charlotte-Douglas International Airport in North Carolina in September with controllers at multiple FAA facilities and the American Airlines ramp tower using NASA technology to manage live traffic operations.

The integration of unmanned aircraft systems, or UAS, into the airspace also took steps forward over the past year. A series of **flight demonstrations of small UAS in low-altitude airspace** (i.e., below 500 feet) was conducted in May and June at FAA-approved test sites across the country. Known as the UAS Traffic Management National Campaign, this collaborative effort among NASA, the FAA, industry and academia focused on close-proximity beyond-visual-line-of-sight operations in sparsely populated areas. Future UTM demonstrations will focus on moderately populated areas and higher-density urban areas. The UAS community will need to work together with the broader aviation community to demonstrate that these systems can be operated safely with regard to other vehicles in the air and people and property on the ground.

Besides UAS, a wide range of other novel aircraft have emerged. For instance, Uber Elevate announced in April that it is working toward flight testing of air taxis in the Dallas-Fort Worth area, Los Angeles and Dubai by 2020. In addition, several companies have been designing and testing personal air vehicles, including Slovakia-based AeroMobil, which started taking pre-orders in April for its initial production run of 500 vehicles. In June, Colorado-based Boom Technology announced 76 firm orders for its supersonic transport, with planned service entry in 2023. Like UAS, these aircraft must be integrated into the airspace in a safe and efficient manner. ★

Contributors: James Cistone, Richard Coppenbarger, Frank Frisbie, Shahab Hasan, Joseph Post, Aditya Saraf, Peng Wei

▲ **A pilot** controls a small unmanned aircraft at a New York test site for the NASA Unmanned Aircraft Systems Traffic Management program.

Airbus, Boeing airliners make first flights

BY IMON CHAKRABORTY, MICHAEL DRAKE AND MATTHEW ORR

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



It has been an eventful year for the aerospace and aviation industries. In commercial aviation, the Boeing 787-10 had its nearly five-hour first flight out of Boeing's facility in North Charleston, South Carolina, in March. The newest and longest 787 family member is powered by two General Electric GENx-1B or Rolls-Royce Trent 1000 TEN engines.

Boeing's 737 MAX program also had a busy year, with first flight of the CFM Leap 1B-powered MAX 9 in April, followed by first airline delivery of the 737 MAX 8 to Malaysian carrier Malindo Air in May, and launch of its newest and largest variant of the family, the 737 MAX 10, at the Paris Air Show in June. The 737 MAX program, with more than 4000 orders from 93 customers, is the fastest-selling aircraft in the company's history.

Airbus had notable firsts as well. In April, it delivered the first A321neo, the largest member of the A320 family, to launch customer Virgin America (part of Alaska Air Group). This aircraft, powered by two CFM International Leap-1A or Pratt and Whitney PW1100G turbofans, offers significant fuel burn and noise reductions over previous generation aircraft.

In October, the Airbus A330neo made its first flight at Blagnac in Toulouse, France. An 1,100-hour flight test campaign for the 287-PAX A330-900neo variant is scheduled for FAA and European Aviation Safety Agency type certification in mid-2018. Powered by the latest-generation Rolls-Royce Trent 7000 engines, the aircraft is slated to reduce fuel consumption 14 percent relative to the original A330.

▲ **Boeing's 787-10** makes its first flight on March 31.

China's challenger to the Airbus A320 and Boeing 737, the COMAC C919, made its first flight in May 2017. The C919 has 730 orders from 27 different customers. Bombardier Commercial Aircraft delivered its first C-Series CS300 aircraft to airBaltic in December 2016. In May 2017, Swiss International Air received its first CS300 aircraft. The airline became the first to operate both C-Series models and, in August, completed the first C-Series revenue service with a CS100 between Zurich and London City Airport.

In 2017, numerous companies presented concepts for on-demand mobility, electric/electric hybrid propulsion and autonomy aircraft, with several flight test demonstrations taking place.

In June, Airbus Helicopters, in collaboration with Helicopteres Guimbal, announced it had begun autonomous flight trials of the VSR700 Optionally Piloted Vehicle demonstrator. The vehicle took off, hovered, performed maneuvers and landed with a human "safety" pilot on board.

In April, the prototype electric-powered vertical takeoff and landing Lilium jet made its first test flights near Munich. While the prototype was remotely piloted, the long-term vision is to launch a piloted five-seater version.

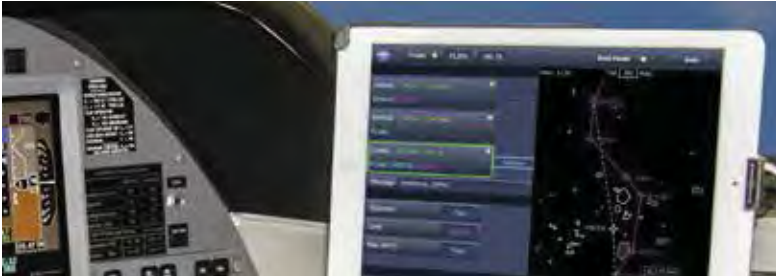
On Sept. 25, German company Volocopter GmbH demonstrated its 18-rotor Volocopter all-electric VTOL autonomous urban flying taxi prototype in Dubai.

In April, Aurora Flight Sciences demonstrated a quarter-scale model of the eVTOL air taxi it's developing for the Uber Elevate urban air transport network in collaboration with Berlin-based BCG Digital Ventures.

In military aviation, the Boeing/Saab T-X trainer continued its flight test program this year; its first flight was Dec. 20, 2016. The clean-sheet design aims to replace the aging Air Force T-38 Talon aircraft with compatibility with fifth-generation fighters like the F-22 Raptor and F-35 Lightning II aircraft. The advanced cockpit, twin-tailed trainer is powered by a single GE F404 engine. Bell's V-280 advanced tilt-rotor was slated for first flight before the end of the year. Northrop Grumman subsidiary Scaled Composites flew its Model 401 demonstrator in October.

In aviation research, the Perlan 2, a two-seat, pressurized experimental glider, set a glider world altitude record of just over 52,000 feet in September. In October, Lockheed Martin submitted its proposal for the X-plane for the Quiet Supersonic Transport, or QueSST, low boom demonstrator. ★

Contributors: Roelof Vos, Bill Crossley, Ruben Perez and Charlie Svoboda
Michael Drake and Matthew Orr work for Boeing.



NASA, FAA roll out apps for improved flight efficiency

BY JOHN H. KOELLING AND TOM REYNOLDS

The **Aircraft Operations Technical Committee** promotes safe and efficient flights by encouraging communication and interchange of relevant concerns, ideas and initiatives across the stakeholder community.

The use of Electronic Flight Bag applications by pilots grew this year. Alaska Airlines began integrating NASA's Traffic Aware Planner app on three Boeing 737-900ER jets. With TAP, a pilot can send a route optimization request to air traffic controllers to reduce flight time and save fuel as provided under NASA's Traffic Aware Strategic Aircrew Requests concept.

NASA's Airspace Technology Demonstrations project continued to develop and demonstrate advanced concepts to identify promising techniques for transition to the FAA. The ATD-1 team transferred the Terminal Sequencing and Spacing software, NASA's 2017 Software of the Year. The ATD-1 team also demonstrated a prototype of **Flight-deck Interval Management avionics** aboard a Boeing 787. The ATD-2 team's Integrated Arrival/Departure/Surface Management software, which integrates these factors for metroplex environments, was scheduled to go live at Charlotte Douglas International Airport in North Carolina this year. ATD-3 finalized its air/ground integration concept, which improves efficiency and throughput for the en route and arrival phases of flight by integrating advanced ground and flight deck technologies, including the TASAR concept.

As of August, FAA Data Communications tower services, in which controllers send messages to pilots digitally, had been deployed at 55 airports. Initial en route services are expected to be deployed in 2019 and available across the National Airspace System by 2021. With Data Comm, controllers send departure clearance instructions to flight crews by text rather than by voice over radio. This speeds up the clearance process, reduces operational errors and permits more complicated messaging, such as changes to optimize operations over an entire flight route.

Also this year, Aireon, a joint venture of Iridium and four air navigation providers, began validating its collecting of space-based Automatic Dependent Surveillance-Broadcast messages from aircraft. The **Iridium NEXT satellite constellation** that provides this capability reached 20 satellites in orbit in June, following the launch of the first 10 satellites in January. Another 55 satellites are scheduled to be launched to enable a fully operational system by mid-2018. This technology has the potential to revolutionize air traffic control services by providing worldwide surveillance of commercial aircraft and helping identify inefficiencies and associated mitigations for improved aircraft operations on a global scale.

To improve air traffic management in the National Airspace System, NASA this year began transferring to FAA and MITRE Corp. the clear-weather portion of the Integrated Demand Management concept. IDM integrates NextGen's strategic Traffic Flow Management System and the more tactical Time-Based Flow Management system. Integrating these software tools creates a gate-to-gate framework so that traffic managers can more readily identify when demand exceeds forecasted capacity and find a resolution. Researchers are now focused on expanding the concept for convective weather operations to reduce delays, improve throughput and facilitate user-preferred trajectories.

Over the course of four weeks in May and June, the NASA-led **Unmanned Aircraft System Traffic Management team conducted its second National Campaign flight test** involving collaboration with industry, and including multiple vehicles and concepts at six FAA UAS test sites. Researchers made great progress this year toward safely enabling UAS operations in low altitude (below 400 feet) airspace. NASA, FAA, other federal agencies and industry are exploring UTM concepts, data exchange requirements and a supporting framework to enable multiple beyond visual line-of-sight UAS operations in airspace where FAA air traffic services are not provided.

The FAA this year continued operational evaluation, flight test and refinement of the **Airborne Collision Avoidance System Xa software** for conventionally piloted aircraft and ACAS Xu for unmanned aircraft. Also, the Standard Terminal Automation Replacement System reached a milestone with its introduction in 70 terminal radar approach control facilities, including the "Big 11" that control 80 percent of the arriving and departing traffic at U.S. airports. By 2019, STARS will be operational at more than 150 civil and more than 80 military TRACONS. ★

Contributors: Tamsyn E. Edwards, Gabriele Enea, Antony D. Evans, Rania Ghatas, Michiel J. Schuurman

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Real-world applications, support for Starline test

BY PAUL VOSS

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

In 2017, balloon systems saw significant advances in navigation, station keeping and commercial application. Alphabet's Project Loon used its stratospheric balloons to provide internet connectivity to tens of thousands of people in historic flooding around Lima, Chimbote and Piura, Peru. Working in collaboration with Telefonica, Loon balloons served people over a 40,000-square-kilometer area roughly the size of Switzerland and transferred about 160 gigabytes of data. In October, the FCC gave Project Loon permission to provide internet in Puerto Rico after Hurricane Maria devastated the island territory.

In February, Oregon-based Near Space Corp. supported a parachute system qualification test for Boeing's new CST-100 Starliner spacecraft. The Starliner is being developed in collaboration with NASA to provide the United States with a crew space transportation system for servicing low Earth orbit destinations, such as the International Space Station. The test involved taking a representative test article (shape and mass) to an altitude of about 40,000 feet and releasing it on a programmer chute to achieve the same flight conditions the actual capsule would achieve on its return descent from orbit. The test used a custom, heavy-lift balloon and specialized ground equipment that provided a static launch of the spacecraft and allowed the balloon inflation to be carried out prior to being attached to the test article. Through additional balloon flights, Boeing will demonstrate the Starliner's ability to land safely on land, a first for a U.S. space capsule.

Raven Aerostar balloons logged over 10,000 flight days in the stratosphere this year supporting research, development and operational objectives. In June, a 10-day flight demonstrated mid-latitude waypoint navigation and station seeking. Launched from Raven's Flight Operations Center in South Dakota, the balloon navigated by wind shear to a target area in Oklahoma and then performed altitude changes to remain within 40 nautical miles of the target for three days. The balloon was then directed to a second target area in West Texas, traveling for two days and remaining within 30 nautical miles of the target for another day before being terminated.

Researchers at Smith College conducted two flights of their controlled meteorological balloons in Antarctica. The two 230-gram (payload mass) balloons flew for three and 6½ days respectively, with the later navigating 2,800 km across the continent from Aboa Station in Queen Maud Land to the Ross Ice Shelf and performing a controlled landing on the ice midway through the transit.

The NASA Balloon Program's Antarctic campaign staged five flights from McMurdo Station. The three larger payloads (over 2,000 kilograms) each flew over 20 days, one flew for 30 days, and two were fully recovered this same season. NASA launched a 532,200-cubic-meter super pressure balloon in May from New Zealand that carried the Extreme Universe Space Observatory experiment. While the science mission was successful, the balloon performance was not optimal, and the mission ended after 12 days through a controlled termination. The fall Fort Sumner, New Mexico, campaign was to include eight science and student payload flights. In March, the NASA Explorers Program selected the Galactic/Extragalactic Ultralong-Duration Balloon Spectroscopic Terahertz Observatory to fly a 100-day-plus super pressure balloon mission in 2021 from Antarctica.

World View accelerated development and testing of its Stratollite vehicle, a long-duration stratospheric balloon designed for commercial payloads up to 50 kilograms. To date, World View has demonstrated altitude control, steering and station-keeping on multiple Stratollite missions, all carrying a variety of commercial and government payloads. In October, World View celebrated the opening of its new stratospheric launch facility, Spaceport Tucson, and 13,200-square-meter global headquarters, housing balloon manufacturing, mission control and research. ★

Contributors: *Debbie Fairbrother (NASA), Tim Lachenmeier (Near Space Corp.), Matt Mulhern (Alphabet), Sebastian Padilla (World View) and Mike Smith (Raven Aerostar)*



▲ **Raven Aerostar** launches a balloon on a 10-day mission in June.

Raven



U.S. Air Force

◀ **The F-16 VISTA aircraft** of the U.S. Air Force Test Pilot School demonstrated the autonomous wingman.

Efficiency and capability drive flight testing in 2017

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.

Boeing completed multimonth flight test of the 737-8 MAX aircraft, culminating in FAA and European Aviation Safety Agency certification in March. The 737-9, the second MAX variant, began flight testing in April. The re-engined 737 MAX family delivers fuel burn improvements of around 10 percent. As aircraft manufacturers test and field improvements to meet increasing demand for fuel-efficient airliners, the MAX is widely viewed as Boeing's response to the re-engined Airbus A320neo.

Dassault Aviation's Falcon 5X completed its first flight in July, beginning a preliminary flight test series to speed development ahead of next year's full flight test campaign. Continuing the theme of efficiency improvements, the new design aims to be the tallest and widest in its class while still delivering significantly lower fuel burn.

In August, NASA's Armstrong and Langley research centers commenced the second phase of flight tests to evaluate the aeroacoustic performance of several airframe noise reduction technologies. These included the Adaptive Compliant Trailing Edge flap, main landing gear porous fairings and gear cavity treatments installed on two Gulfstream G-III testbed aircraft. A 185-microphone phased array capable of identifying closely spaced noise sources took the extensive acoustic measurements. The resulting database will serve to validate the simula-

tion-based airframe noise prediction approach used to design and develop the tested landing gear technologies.

In flight test training and education, the U.S. Air Force Test Pilot School, in partnership with the Air Force Research Laboratory, Lockheed Martin and Calspan, demonstrated the Have Raider II autonomous wingman architecture in flight testing made public in April. The school's F-16 Variable In-Flight Simulator Test Aircraft, or VISTA, operated as a surrogate "loyal" wingman, coordinating various combat maneuvers with a manned aircraft. Developing such capabilities to safely test combinations of classical aircraft and unmanned aircraft systems has become vital as they increasingly mingle in operational airspace.

In May, Virgin Galactic's second SpaceShipTwo craft tested its atmospheric re-entry system during a gliding test flight, an incremental step in transitioning to powered tests. With this redesigned system, the company continues its long-suspended flight test program following a fatal flight test accident in October 2014. The current test program furthers the company's plan to commence commercial space tourism flights in 2018.

From June through August, over 50 small UAS flight tests were completed at the City Environment for Range Testing of Autonomous Integrated Navigation test range at NASA's Langley Research Center. Teams investigated various integrated air-ground systems as enablers for safe autonomous small UAS operations beyond visual line-of-sight and near/over populated areas. Data from this project support joint NASA-FAA work to develop and implement a UAS traffic management system into the National Airspace System. ★

Contributors: Paul Bolds-Moorehead, Bruce Owens and Brent Cobleigh



U.S. Air Force Research Lab

Hypersonic work emphasizes practicality

BY HOWARD "GREG" JOHNSTON AND KEVIN G. BOWCUTT

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

▲ **The HIFiRE Flight 4** hypersonic glider was tested at Australia's Woomera Test Range.

Research and development in hypersonics was aggressively pursued this year in several countries, pushing the science and engineering aspects of the field toward practical applications. Along this path, government, industry and academic institutions continued to work together to develop modeling and computational simulation capabilities, conduct ground and flight tests, mature enabling technologies and design operational systems for a new era of hypersonic flight.

The German Aerospace Center, DLR, this year compared simulations to the sounding-rocket data from the 2016 Rocket Technology Experiment-Transition, or ROTEX-T, mission. Researchers found reasonable agreement for laminar and turbulent heat fluxes during hypersonic boundary layer transition. ROTEX-T was launched on a spin-stabilized two-stage sounding rocket that reached Mach 5.4 and measured aerothermal phenomena at high-sampling rates of up to 2 megahertz.

JAXA, the Japan Aerospace Exploration Agency, decided this year to increase the Mach number to 5 for its pre-cooled turbine-based engine. JAXA plans to ground test this system at that speed in 2018. Mach 4 testing was conducted in 2016.

China was focused on key basic scientific issues associated with near-space, long-range, maneuverable hypersonic vehicles flying at altitudes of 30 kilometers to 70 kilometers.

The Indian Space Research Organization in March commissioned a hypersonic shock tunnel

that is the third largest in the world in terms of simulation capabilities. The tunnel is at the Vikram Sarabhai Space Center.

At the Aerospace Systems Directorate of the U.S. Air Force Research Laboratory, or AFRL, in Ohio, funded programs include GOLauncher 1, a single stage booster for hypersonic research that in September completed subscale aerodynamic wind tunnel testing at subsonic to hypersonic speeds.

Also, at AFRL and other agencies, airframe and propulsion teams have been refining propulsion requirements via a turbine-based combined-cycle vehicle architecture study. At the conclusion of the architecture study, critical ground-based propulsion experiments will begin.

In June, an Australia-led team executed a hypersonic aerosciences experiment at the Woomera Test Range, South Australia. The team met the principal research objective of demonstrating the controlled atmospheric entry, pull-up, glide and aerodynamic maneuver of the hypersonic vehicle. The flight team partnered with Boeing, the University of Queensland, DLR and BAE Systems to develop the experiment, which was carried out under HIFiRE, the Hypersonic International Flight Research Experimentation program. HIFiRE traces its roots to 2006, when AFRL's High Speed Aerospace Systems Directorate joined forces with the Australian Defence Science and Technology Group to develop and experimentally validate technologies deemed critical to the realization of next generation hypersonic strike and global reach capabilities. The HIFiRE team this year worked toward completing the final design, development and ground testing of the two remaining aero-propulsion flight experiments.

The Brazilian Space Agency this year joined the European Space Agency-led High-Speed Experimental Flight Vehicles-International initiative, or HEXAFly-INT. Researchers are assessing vehicle designs for a high-speed civil transport. Brazil started the assembly of a new hypersonic facility and continues its experiments with laser-ignited hydrogen supersonic combustion.

In August, HEXAFly-INT tests were conducted on a model of a high-speed civil transport at Russia's TsAGI T-116 Wind Tunnel. Also this year, the idea was broached of conducting HEXAFly-INT launches from Russia's newly constructed Vostochniy launch site. ★

Contributors: Thomas A. Jackson, Douglas J. Dolvin, Barry M. Hellman, AJ Piplica, Joaquin H. Castro, Johan Steelant, Ali Gülhan, Masataka Maita, Marco Minucci and Dvoynikov Alexander

Hybrid airships move closer to commercial flight

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.

Proponents of hybrid airships that derive part of their lift from helium and the rest from aerodynamics gained momentum toward building a new market for their aircraft.

Hybrid Air Vehicles' Airlander 10, following damage sustained in a nose-down, hard landing late in 2016, returned to the sky in May, modified to include such safety features as two thimble-shaped, 10-foot-long bumper bags mounted on each side of the bridge. During flight, the bags lie flat, but during landing they can be air-inflated in 20 seconds to protect the bridge against collision with large fixed objects, including the ground. In September, the European Aviation Safety Agency deemed Airlander ready for customer trials and granted Hybrid Air Vehicles permission to make higher, faster and more distant test flights from its Cardington, Britain, base, which the company says it will soon vacate.

In October, **Hybrid Air Vehicles signed two deals to create a luxury-tourism variant of Airlander**. One, with British travel purveyor Henry Cookson Adventures, anticipates a first tourist flight in 2018. The other, with aircraft interior designer

▼ **The ADB-3-XO1**, made by Airship do Brasil, is the first manned airship built in Latin America.



Airship do Brasil

Design Q, calls for that company to create a special tourism configuration for the Airlander's gondola. A statement released by the three companies imagines tourist trips to the the North Pole, Bolivia's Salt Flats and the Namib Desert.

Lockheed Martin, whose LHM-1 hybrid airship is still in development, said in April it had entered into a strategic partnership with gas exploration and refining company Helium One to use its airships to transport liquefied helium from wells in Tanzania to the African coast for shipment. Helium One said its' deposits contain nearly 100 billion cubic feet of the gas--enough to "alleviate fears of a global shortage for decades to come." Helium is used for lighter-than-air craft, welding, underwater breathing gases and other technologies. Hybrid Enterprises, exclusive reseller for LMH-1, signed a letter of intent in June for a deal valued at \$500 million with France's Hybrid Air Freighters to sell the French company up to 12 LMH-1 airships, starting in early 2020. The deal follows a similar announcement last year that Hybrid Enterprises had signed a letter of intent to sell 12 LMH-1s to Britain's Straightline Aviation.

Brazil, birthplace of airship pioneer Santos-Dumont, on July 24 celebrated the **inaugural flight of the first manned airship built in Latin America**. The ADB-3-XO1, made by Airship do Brasil, is an update of U.S. Lighter Than Air Corp.'s type-certified 138S from the 1980s. The Brazilian airship company considered less traditional designs but chose this one for its ability to hover while delivering cargo to jungle sites too small for a hybrid airship to land. With 3-XO1, the company said it has joined the ranks of only six companies in the world able to complete a full research-and-development cycle for building an airship.

Goodyear in February retired its last blimp, "Spirit of Innovation," replacing it with "**Wing-foot Two**," a **semi-rigid Zeppelin NT** that arrived in Long Beach, California, in late October. It had completed a 10-state journey from Akron, Ohio, under the command of Taylor Deen, one of two female pilots of lighter-than-air craft in the world. The new dirigible will be housed in an inflatable, nine-story "air dock" at Goodyear's base in Carson, California.

Walmart in February filed a patent for a lighter-than-air warehouse — a dirigible that could carry package-delivering drones. The U.S. Patent and Trademark Office had previously granted a similar patent to Amazon that envisioned a high-altitude "monitoring station" that would keep track of delivery drones and that, when flying at lower altitudes, could deliver packages itself. ★



Lockheed Martin

program has completed 14 flights with 20 hours in the air, and in 2017, it demonstrated unique maneuvers and handling qualities at speeds up to 150 knots at Sikorsky's Development Flight Center in West Palm Beach, Florida. In 2018, Sikorsky plans to achieve speeds above 220 knots and to continue demonstrating the mission capabilities of this next-generation light tactical prototype helicopter, capable of twice the cruise speed and maneuverability of conventional armed scout helicopters.

V-22s sold to Japan; electric aircraft being developed

BY ERASMO PIÑERO

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

▲ A test pilot flies an F-35B Lightning II during an asymmetric loading test flight.

The F-35 aircraft program reached a major public milestone when it performed a routine at the Paris Air Show in June. Lockheed Martin test pilot Billie Flynn demonstrated the aircraft's agility. While unit costs, Red Flag military exercise deployments and international participation on the program grabbed headlines, the flight test program continued uninterrupted with flight test hours reaching 100,000 to date. This year, the F-35B testing included live weapons trials, ski-jump testing and powered lift mode formation flights. In January, the U.S. Marine Corps deployed a squadron of F-35Bs to its overseas base in Iwakuni, Japan — the aircraft's first deployment outside the continental U.S.

The Japanese Self-Defense Forces are poised to receive the first of 17 Bell Boeing V-22 Osprey tiltrotor aircraft, which was rolled out at the Bell Amarillo, Texas, facility in October. This is the **first foreign military sale of the V-22.**

Sikorsky, a Lockheed Martin company, continued testing the proof of concept S-97 Raider compound helicopter, based on its X2 Technology. This aircraft is focused on demonstrating future vertical lift capabilities for the U.S. Army. The Raider

Additionally, Sikorsky is teamed with Boeing to focus on Future Vertical Lift medium requirements for the **SB>1 Defiant Technology Demonstrator** aircraft for the Joint Multi Role Technology Demonstrator program. Like Raider, Defiant is a rigid coaxial design with a pusher propeller based on X2 Technology. In August, engines were started for the first time on the Defiant Propulsion System Testbed. First flight is expected in mid-2018. In the meantime, Bell Helicopter announced in September that the V-280 Valor tiltrotor demonstrator is complete. Ground testing began in late September at a purposely built elevated ramp at the company's Amarillo facilities. First flight of the V-280 was expected by year's end.

On other powered lift applications, Aurora Flight Sciences continued developing the **XV-24A LightningStrike** X-plane. The XV-24A is a DARPA-funded tilt-wing hybrid-electric unmanned demonstrator. The aircraft demonstrated its control architecture on a subscale unmanned prototype. This 159-kilogram, 20 percent-scale flight demonstrator completed its flight test program in April.

2017 was a breakout year for electric vertical takeoff and landing aircraft, spurred by the April launch of Uber Elevate, which seeks to engender a VTOL urban transportation system of electric air taxis. Some 30 companies around the world are known to be developing electric and hybrid-electric VTOL aircraft, basically extending the technology and concepts of electric VTOL drones to manned aircraft. ★



Sylvain Ramadier/Airbus

delivered 995 airplanes at a value of \$9 billion during the first half of 2017. Global business jet shipments increased by three units to 295 deliveries over the first six months of 2017. The rotorcraft industry delivered 465 aircraft in the first six months of 2017, an increase of 16.8 percent compared to the same period last year, and the value of the deliveries was \$1.9 billion compared to \$1.5 billion for the first six months of 2016.

Industry sees increased profits, major acquisitions

BY VENKATESAN SUNDARARAJAN

The **Economics Integration and Outreach Committee** analyzes the economic aspects of aerospace programs and technology.

▲ **Airbus' A330neo** makes its first flight in October. In a year that saw several blockbuster acquisitions, Airbus said it was buying a majority stake in Bombardier's C Series aircraft.

The global aerospace and defense sectors recorded revenue of \$709 billion in 2016 compared with \$689 billion in 2015, an increase of 3 percent, according to the "Aerospace & Defense 2016 year in review and 2017 forecast" report published by PricewaterhouseCoopers in June. The operating profits for the two sectors were \$69 billion, an increase of 7 percent from \$64 billion in 2015. The industry's operating margin improved by 40 basis points to 9.7 percent in 2016 from 9.3 percent in 2015. In constant U.S. dollars, global aerospace and defense sector growth was 2.4 percent in 2016, slightly outperforming global gross domestic product growth of 2.3 percent, according to Deloitte's "2017 Global aerospace and defense sector performance study," published in July. This growth was driven primarily by the European commercial and U.S. defense subsectors.

The global commercial aerospace subsector revenue increased from \$314.7 billion in 2015 to \$323.1 billion in 2016, but the growth slowed from 6.3 percent in 2015 to 2.7 percent in 2016. The European subsector recorded 6.7 percent growth, while U.S. growth was 1.3 percent. The commercial aircraft delivery was at a record high of 1,436 aircraft in 2016 compared to 1,397 in 2015. According to the General Aviation Manufacturers Association, the general aviation industry

The sector recorded merger and acquisition deals worth \$38 billion in 2016. During the first half of 2017, \$18 billion in mergers and acquisitions were realized through 25 deals that disclosed each had a value greater than \$50 million. In June, shareholders of Safran SA approved the plan to buy Zodiac Aerospace for \$7.7 billion after Zodiac accepted a 15 percent cut from the original offer of \$9 billion. In September, United Technologies completed a definitive agreement to buy Rockwell Collins for \$30 billion.

In 2016, the global space economy totaled \$329 billion worldwide, according to "The Space Report 2017" by the Space Foundation. Commercial space activities made up 76 percent of the global space economy, valued at \$253 billion. The U.S. government spent \$44 billion on defense and nondefense space efforts in 2016, a 3 percent increase from 2015. The NASA budget for fiscal 2017, which ended Sept. 30, was \$19.025 billion, compared to an actual budget of \$19.285 billion for fiscal 2016. NASA awarded a total of \$18.26 billion in contracts for fiscal year 2016, up 10 percent from \$16.60 billion a year earlier. The Russian Space Agency was the largest foreign contractor for NASA, valued at \$236 million.

In August, the U.S. Air Force awarded Boeing and Northrop Grumman separate contracts to continue work on replacing the Minuteman 3 intercontinental ballistic missile. Northrop Grumman was awarded \$328 million and Boeing \$349 million over the three-year contract. In January, NASA awarded an additional four crew rotation missions each to commercial partners Boeing and SpaceX to carry astronauts to and from the International Space Station as part of the agency's Commercial Crew Program. ★

Programs encourage carbon-emission reductions

BY GARY DALE

The **Green Engineering Integration and Outreach Committee** promotes a holistic, systems approach to improved energy efficiency, sustainability, renewable energy and design.

International Civil Aviation Organization member states in March forged a consensus that launched the **Carbon Offsetting and Reduction Scheme for International Aviation** to address any annual increase in total carbon dioxide emissions above 2020 levels from international civil aviation. Beginning in 2020, under CORSIA, operators of international flights will be required to purchase offsets for the growth in CO₂ emissions.

Airports moved ahead with plans to focus on the environmental impact of their operations. In February, London's Heathrow Airport announced it would make the effects of its new fourth runway carbon neutral and establish a center of sustainability excellence "for sustainability at airports and in the wider aviation sector." India's Mumbai airport achieved carbon neutrality in the Airport Carbon Accreditation certification program in May.

In January, the Port of Seattle, Boeing and Alaska Airlines released the **Biofuel Infrastructure Feasibility Study**, which is considered a step in Seattle-Tacoma International Airport's goal of supplying up to 50 million gallons of aviation biofuel per year.

Sweden and the United States have collaborated on certification of catalytic hydrothermal conversion-to-jet biofuel, or CHCJ-5. At its facilities in Linköping, Sweden, in April, Saab Gripen conducted test flights with 100 percent CHCJ-5 made of rapeseed oil. This was the first time a single engine fighter flew with 100 percent biofuel. Applied Research Associates worked with the U.S. Navy to develop and test CHCJ-5, which culminated in a flight test at Naval Air Station Patuxent River, Maryland, of an EA-18 Growler aircraft, performing just as with JP-5, with 80 percent fewer greenhouse gas emissions.

On Sept. 30, NASA awarded a limited series of risk-reduction contracts to help industry contenders reduce technology risk and maintain momentum before the first **Ultra-Efficient Subsonic Technology X-plane** demonstrator flies in the mid-2020s. Aurora Flight Sciences was awarded work for its D8 double-bubble design. Boeing received study contracts for both blended-wing



▲ **Clean Sky's Breakthrough Laminar Aircraft Demonstrator** in Europe, or BLADE, was flight-tested in September. The aircraft has two transonic laminar outer wings. The goal is to reduce skin friction drag, lowering carbon dioxide emissions up to 5 percent.

body and transonic truss braced wing concepts. The risk-reduction tasks are focused on design and analysis activities through September 2018.

In October in Connecticut, Pratt and Whitney conducted an engine ground test demonstration of ultra-high bypass technologies under the FAA's Continuous Lower Energy, Emissions and Noise Program. It is hoped these technologies will contribute to reduced aircraft noise and fuel consumption.

In April, Aurora Flight Sciences, Mooney International and Airspace Experience Technologies unveiled their electric vertical takeoff and landing aircraft concepts at Uber's Elevate Summit. Also in April, Germany-based Lilium Jet completed an unmanned flight test of a prototype two-seater — a compact, lightweight electric plane capable of vertical takeoff and landing. Germany-based E-voLo, whose concept is the VoloCopter, agreed to a finance deal for over 25 million euros from automobile firm Daimler and other investors. In September, Dubai staged a test flight of the VoloCopter. In April, it was announced that Boeing's HorizonX and JetBlue's Technology Ventures are investing in Zunum Aero, a startup based in Washington state that's developing an electric-powered aircraft, targeting regional, short-haul routes for 10- to 50-seat aircraft.

Also this past year, Tohoku University and Mayekawa in Japan developed a **new hybrid energy storage system** comprised of electric and hydrogen energy storage systems, which combines the effective utilization of renewable energy at normal times and the ability to be a power source during emergencies. Scotrenewables Tidal Power reported its SR2000 floating tidal turbine deployed for testing at the European Marine Energy Center achieved its rated 2 megawatt capacity in April. And E.ON worked on developing a demonstration site for airborne wind technology in Ireland. ★

Contributors: Committee members

A nod to tragic and triumphant events

BY RICHARD P. HALLION

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

This year saw many anniversaries, some marking tragic events.

The 50th anniversary of the Apollo 1 disaster was Jan. 27. Apollo astronauts Virgil “Gus” Grissom, Edward White II and Roger Chaffee died when their command module caught fire during a pre-launch checkout at Launch Complex 34 at NASA’s Kennedy Space Center. On Jan. 24, Johnson Space Center in Houston held a commemoration and astronaut Nicole Mann moderated a panel in which Apollo astronauts Walt Cunningham and Frank Borman spoke of how lessons learned from the tragedy could be applied today.

On April 11, Gallaudet University in Washington, D.C., opened an exhibit commemorating the “Gallaudet 11,” a group of deaf men whose damaged vestibular systems prevented them from experiencing motion sickness. NASA and the U.S. Naval School of Aviation Medicine recruited the men to participate in an experimental program from 1958 through 1968 that took them from zero-gravity parabolic flights in NASA’s KC-135 Stratotanker aircraft (the infamous “Vomit Comet”) to a pitching, heaving ferry off the coast of Nova Scotia.

April 18 marked the 75th anniversary of the famed World War II raid on Tokyo and other targets by a flight of 16 B-25 bombers launched from the aircraft carrier USS Hornet and commanded by U.S. Air Force Maj. James Doolittle.

The 75th anniversary of the Battle of Midway was June 4-7. U.S. Navy SBD Dauntless dive bombers designed by Edward Heinemann sank four Japanese carriers and one heavy cruiser. It was the turning point in the Pacific war.

NASA’s Langley Research Center celebrated its centenary with a series of events, including the opening of the Katherin G. Johnson Computational Research Facility. For a century, Langley has stood at the forefront of American air and space research — from the dawn of aeronautics into the age of astronautics. The fingerprints of its research staff are on every significant American aerospace development, from the wood-and-fabric biplanes of the “Great War” to robotic

spacecraft that leave the Earth for solar system exploration and beyond. Fittingly, the centenary also coincided with commemorating Langley’s African-American female mathematicians whose previously hidden history has been memorably told in Margot Lee Shetterly’s book “Hidden Figures: The American Dream and the Untold Story of the Black Women Mathematicians Who Helped Win the Space Race” and the film it spawned.

On Sept. 15, the NASA Cassini spacecraft mission ended after nearly 20 years. Launched in 1997, Cassini spent 13 years in Saturn’s orbit before taking a final plunge through its rings and into its atmosphere, meeting a swift and fiery death. NASA mission controllers elected to safely destroy the aging spacecraft rather than eventually losing control of it and it plunging into one of two Saturn moons, Enceladus or Titan, which researchers have concluded are possibly habitable environments or at least “pre-biotic.”

On Sept. 21, a dozen former Vietnamese MiG pilots met with U.S. fighter pilots who had flown against them. The reunion in San Diego included a reception on the USS Midway, a carrier turned museum from whose decks naval aviators had launched in Alpha Strikes against then-North Vietnam a half-century ago. Both groups welcomed each other warmly. “We were doing our jobs,” said Vietnamese Senior Col. Nguyen Van Bay, speaking for all, adding “That’s the past. Now, we’re friends.”

Finally, Oct. 1 marked the 75th anniversary of the first U.S. turbojet flight by Robert Stanley in the Bell XP-59A, and Oct. 3 marked the 50th anniversary of the fastest-ever airplane flight at Mach 6.70 by U.S. Air Force test pilot Maj. William “Pete” Knight in an X-15. ★

▼ **NASA Langley Research Center**

employees mark its 100th anniversary in front of its historic flight test hangar.



NASA



JOEL KOVSKY/NASA

of the concerns of the commercial space industry and expedite the commercial remote sensing licensing process. The American Space Commerce Free Enterprise Act of 2017 would move many responsibilities for the review of space activities away from the FCC, FAA and NOAA to the Department of Commerce's Office of Space Commerce in an effort to streamline the review process. At press time, the bill was

▲ **The U.S. National Space Council's** first meeting was Oct. 5 at the Smithsonian National Air and Space Museum's Steven F. Udvar-Hazy Center in Chantilly, Va.

Space commerce, drones draw legal interest

BY JESSICA SWEENEY NOBLE AND DAN BLAKESLEE

The **Legal Aspects of Aeronautics and Astronautics Integration and Outreach Committee** fosters the development, application and operation of space systems and addresses emerging issues in the area.

This year has been one of retrospectives and prospective change for aerospace law and policy. The 50th anniversary of the signing ceremonies for the United Nations Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies was in January. This milestone prompted many, including U.S. Sen. Ted Cruz, R-Texas, chairman of the space subcommittee of the Senate Committee on Commerce, Science, and Transportation, to examine the efficacy of the 50-year-old treaty.

The subcommittee held three hearings over the summer under the heading of Reopening the American Frontier to examine the domestic and international legal framework governing commercial activities in space. There was consensus among the legal experts who testified in the May hearing that the United States should not seek to amend the treaty. Discussion will continue on alternative methods of addressing the legal uncertainties that commercial space companies face, such as international guidelines and domestic regulatory reform.

Legislation was introduced in June in the U.S. House of Representatives to address some

awaiting a floor vote by the full House.

The trend of national legislation favoring property rights in space resources continued in July, when Luxembourg granted companies rights to resources extracted in space and established a license and supervision regime.

In the U.S., President Donald Trump signed the NASA Transition Authorization Act of 2017 in March. It set a \$19 billion budget for NASA for fiscal 2017. In June, Trump signed an executive order re-establishing the National Space Council. Scott Pace, director of the Space Policy Institute at George Washington University in Washington, D.C., was selected to serve as the council's executive secretary.

Drone law continued to be a hot area. In 2015, the FAA started requiring all drones be registered and pay a small registration fee. But, in May 2017, a federal appeals court ruled operators of drones and unmanned aircraft that meet Section 336 of the FAA Modernization and Reform Act don't have to register and may delete their registration and have their fees refunded.

The FAA rolled out a rule that lets pilots use enhanced flight vision systems for landing and rollout from 100 feet and lower. The rule — finalized in December 2016 and effective March 21 — is limited to head-up displays. However, manufacturers have been working on more feature-rich EFVS options with the head-down displays that naturally have more color-rich pixels to work with.

The Trump administration made air traffic control privatization a part of its infrastructure rebuilding program and in June submitted a proposal to Congress, which forwarded it to the Senate Appropriations subcommittee for transportation and housing and the House Appropriations subcommittee for transportation. Both subcommittees rejected the initial proposal. ★



NASA

◀ **People in the United States** from coast to coast looked to the sky Aug. 21 to see a rare total solar eclipse. Joe Matus, an engineer at NASA's Marshall Space Flight Center in Huntsville, Ala., shot this image in Hopkinsville, Ky.

Space geeks and others bask in solar eclipse

BY AMIR S. GOHARDANI

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

Many notable aerospace events excited the public in 2017. From unmanned aircraft systems to new capabilities in aviation and space sectors, it was an exhilarating year for technical innovation and records but some milestones stood out.

In March, FAA Administrator Michael Huerta said more than 770,000 drones had been registered in the U.S., with an increase of 100,000 registrations alone since the beginning of the year. However, in May, a federal court ruled Americans no longer had to register certain hobbyist drones. To address the safety issues of so many UAS in the skies, the FAA aims to expand drone operations, Huerta said, “so they can safely operate over people and beyond a pilot’s visual line of sight.” Huerta further suggested this could be accomplished if authorities are allowed to “remotely identify and track unmanned aircraft during operations.”

Perhaps one of the rarest — and most communal — events of 2017 was the total solar eclipse that crossed the United States. On Aug. 21, the eclipse dominated the nation’s attention as the 70-mile wide path of totality traversed about 3,000 miles from Oregon, where the eclipse

began at 9 a.m. PDT, to South Carolina, which reached totality at 2:49 p.m. EDT. As more than 300 million people in the United States could see the eclipse (at least partially), NASA issued safety tips and recommendations for viewing. NASA’s Goddard Space Flight Center scientist Shawn Domagal-Goldman told cable network CNBC that even people at NASA were concerned about the prospect of the event’s radiation causing “damage to our detectors” and were sure to wear proper eyewear. He said NASA launched “almost 100 high-altitude balloons with camera and sensor packages to study the sun during the eclipse,” ensuring they did not enter high-altitude airline flight paths.

The next full coast-to-coast total solar eclipse will be in 2045. But NASA says the next total solar eclipse visible from the U.S. will take place in seven years, on April 8, 2024. During that eclipse, the moon’s shadow will cross the U.S. border in southern Texas and move up into the eastern half of the country, passing over Dallas-Fort Worth, Cleveland, Buffalo and New York and on to Montreal.

On Sept. 15, the NASA Cassini spacecraft completed its 20-year mission. Cassini launched from Cape Canaveral, Florida, on Oct. 15, 1997, on a mission to orbit Saturn — the only spacecraft ever to do so. NASA project scientist Linda Spilker told The Associated Press that Cassini beamed back information throughout its mission “like a giant firehose, just flooding us with data.” Cassini took more than 450,000 images and sent back more than 635 gigabytes of scientific data during its 294 trips around Saturn. ★



▲ **The European Space Agency's BepiColombo spacecraft** had its final launch readiness tests in July. The Mercury Magnetospheric Orbiter's Sunshield and Interface Structure (MOSIF) that will protect the MMO during the cruise to Mercury is sitting on the floor to the right.

New asteroid missions; Cassini comes to end

BY LEENA SINGH, CHRISTOPHER MOORE AND SURENDRA P. SHARMA

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

In January, NASA's Discovery Program selected two asteroid missions to explore the early history of the solar system. Lucy, to launch in 2021, will pass six Trojan asteroids that lead and trail Jupiter. Trojan asteroids are thought to be remnants of the primordial material that formed the outer planets. Psyche, with a 2023 launch, will survey the asteroid 16 Psyche, believed to be the exposed metallic core of an incipient planet that lost its outer layers in violent collisions.

In March, NASA's Origins, Spectral Interpretation, Resource Identification and Security — Regolith Explorer spacecraft, or **OSIRIS-REx**, collected imagery while scanning for Earth-Trojan asteroids during its passage through Earth's L4 Lagrange point. In August, OSIRIS-REx adjusted course for a gravity-assisted slingshot pass around Earth on its asteroid-sample-return mission headed for Benu.

In April, **Cassini** began its terminal mission phase called "Grand Finale," a series of 22 weekly "dives" into Saturn's atmosphere comprising orbital passes between the planet and its rings before its last plunge into Saturn on Sept. 15. Launched in 1997, Cassini had been in orbit around Saturn since 2004 to study the planet, its rings, moons and magnetosphere. It was the first such in-situ exploration of this region of Saturn.

Voyagers 1 and 2 celebrated their 40th launch anniversaries in August and September,

respectively. They are traversing the heliosphere in opposite directions, telemetering to Earth information about their trajectory encounters. The spacecraft are expected to transmit until about 2030, when NASA plans to switch off their scientific instruments.

The European Space Agency's **Mercury mission spacecraft, BepiColombo**, passed its final launch readiness tests in July in preparation for a 2018 launch. BepiColombo comprises two orbiters, Japan's Magnetospheric Orbiter and ESA's Planetary Orbiter, which will travel together in the Transport Module. The carrier will use a combination of electric propulsion and gravity-assisted passes at Earth, Venus and Mercury to complete the over seven-year transit to Mercury. At Mercury, the orbiters will transfer into distinct orbits, making complementary measurements of Mercury's interior, surface, exosphere and magnetosphere to inform scientists about the origin and evolution of a planet close to its parent star.

In June, ESA's Science Program selected the **Laser Interferometer Space Antenna** trio of satellites, intended to detect gravitational waves from space, as one of its large-class missions. Gravitational waves are ripples in space-time created by celestial objects with very strong gravity, e.g., merging black holes. Albert Einstein's general theory of relativity predicted gravitational waves a century ago, but the ground-based Laser Interferometer Gravitational-Wave Observatory first detected them in 2015. The signal was triggered by two black holes colliding.

NASA unveiled a plan in March for a **Deep Space Gateway** to be launched into lunar orbit. The Orion crew vehicle will dock with this small habitat intended for long-duration, cislunar, crewed missions. The DSG will be used to test critical technologies needed for Mars missions, such as solar electric propulsion, life support systems or autonomous mission operations. Capabilities demonstrated by DSG will drive development of a Mars-ready Deep Space Transport. DST will comprise a larger, long-duration habitat with a 300 kilowatt-class solar electric propulsion system. DSG will be a staging point for assembly, outfitting and fueling of the DST, with initial flight tests scheduled to begin in 2029.

China hit major milestones in its attempt to assemble the China Space Station. In April, the **Tianzhou-1 robotic cargo vehicle** demonstrated China's first in-space refueling when it met the Tiangong-2 orbital module, launched in September 2016. The Tianzhou-1 launched on the Long March 7, China's supply craft launcher. A core space module is scheduled for launch in 2019 to commence on-orbit station assembly. ★

Turning point year for urban mobility, electric aircraft

BY BRUCE J. HOLMES

The **Transformational Flight Integration and Outreach Committee** explores the potential of electric propulsion and autonomy technologies on enabling new aviation missions and markets.

The global aeronautics enterprise stands at the threshold of a transformative epoch for the role of aviation in existing and new markets for commercial, business and private air mobility as well as service innovations. These opportunities are driven by emerging and converging technologies, including innovations in electric propulsion, increasing and more trusted autonomy, manufacturing, airspace management concepts, broadband aviation connectivity and software apps and services. These advancements contribute to the more widespread, safe and efficient movement of people and goods through-out more origins and destinations, utilizing more airspace, in a broader spectrum of vehicle types and business models.

In April, Uber Technologies announced creation of a subsidiary, Uber Elevate, to develop urban electric vertical takeoff and landing, or eVTOL, services. The announcement came at the Uber Elevate Summit in Dallas, where Uber announced partnerships with Dubai and Dallas for urban mobility demonstrations planned for 2020. During the summit, a new venture capital fund (Levitate Capital) for urban air mobility startups was announced, representing a significant event in the aviation startup space, which has not been a traditional sector for investors.

Also in the vertical flight domain, Aurora Flight Sciences in April flew a scaled version of its eVTOL concept. Uber announced selection of the company as a partner for development of aircraft for the Uber Elevate Network. In September, Boeing announced its intent to acquire Aurora.

Turning to electric aircraft, Boeing's Horizon X company and JetBlue announced investments in the hybrid electric-aircraft startup Zunum Aero, of Kirkland, Washington, for regional airline travel. Also in the electric area, eHang of China, Joby Aviation of California, Volocopter GmbH of Germany and dozens of others are involved in eVTOL developments for these new markets.

It was a record-setting year for electric aircraft. In March, the Extra 330LE aerobatic plane, powered by an electric propulsion system made by Siemens of Germany, set two speed records. On March 23 at the Dinslaken Schwarze Heide

airfield in Germany, the piloted aircraft reached a top speed of around 340 kph over 3 kilometers. The next day, the Extra 330LE became the world's first electric aircraft to tow a glider into the sky. The next month, the participants at the AERO Friedrichshafen conference in Friedrichshafen, Germany, witnessed the world's first all-electric air show, including flights by aerobatic aircraft powered by Siemens.

In government developments, the FAA's streamlining of certification processes for CFR 14, Part 23 Airworthiness standards went into effect in August. This streamling paves the way for aircraft incorporating many of the technologies captured in NASA's On-Demand Mobility Technology Roadmaps.

With support from the NASA New Aviation Horizons initiative, NASA is moving forward with the X-57 Maxwell experimental plane for demonstration of innovations enabled in aircraft design through integration of distributed electric propulsion and optimized aerodynamics. In July, NASA took delivery of a Tecnam P2006T fuselage, which will be equipped with modified wings and designated the X-57. The February release of the General Aviation Manufacturers Association Publication 16, a standard for electric aircraft performance, represents a first in this electric technology domain.

The vision for a new generation of urban and regional aircraft for more widely accessible mobility is rapidly evolving. While a global need for such mobility solutions is growing, a spectrum of emerging technologies is increasing the plausibility of bringing such visions to reality. Much challenging work in regulation, policy, finance, public acceptance and infrastructure needs lie ahead. All this context makes it a good time to be an innovator or an entrepreneur in aviation. ★

▼ **Lilium** plans to develop a five-seat jet that will fly commercially. The company says it will be able to travel at up to 300 kph for one hour on one charge, making it more efficient than road taxis.



Lilium GmbH



Space Systems Loral

Communications systems: continued disruption and transformation

BY TOM BUTASH

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

▲ This is an artist's rendering of a Space Infrastructure Services satellite refueling a client satellite on-orbit.

The January death of Harold Rosen, inventor of the first geosynchronous orbit communications satellite and co-recipient of the first AIAA Aerospace Communications Award, was, in retrospect, a harbinger of increasing industry disruption and transformation, which dampened conventional industry commerce during the year. The communications satellite industry faced greater overcapacity and pricing pressures in many markets with a consequential deepening of last year's downturn in service operators' revenue and GSO satellite orders.

Hughes, ViaSat, Intelsat and NBN Co. launched five high-throughput satellites between October 2016 and August 2017. Hughes and ViaSat continued development of their third-generation Ultra HTS GSO systems, while increased venture and other "New Space" investments funded the **development of more than a half-dozen non-GSO HTS megaconstellations**. These include low Earth orbit megaconstellations by Boeing, Hongyun, LeoSat, OneWeb, SpaceX and Telesat — each with between 108 and 4,425 satellites — and seven second-generation SES/O3b medium Earth orbit satellites, which collectively promise to add more than 40 terabits per second of capacity by 2025, according to a Euroconsult study published in June.

Through mid-September, seven GSO communications satellites were awarded, including awards by Indonesia and Thailand — the first by countries with established satellite industries — to the China Great Wall Industry Corp.; Inmarsat's Global Xpress 5 HTS award to Thales Alenia Space; and the Hughes' Jupiter 3 EchoStar XXIV

ultra-high-density satellite to Space Systems Loral. This award pace suggested 10 satellite awards by year's end, an almost **30 percent decline from the 14 awards in 2016**, which had a more than 40 percent decline from the average of slightly over 24 awards during each of the four preceding years.

The commercial downturn was exacerbated by the winding down of the Department of Defense's military communications satellite constellation upgrades. Although the U.S. Air Force in January convened an analysis of alternatives — between procuring military wideband satellites and using commercial broadband satellites — to meet the military's increasing bandwidth needs, no new military communications satellite programs are underway.

SpaceX and Blue Origin continued the race to develop reusable launch vehicles to dramatically lower space access costs. France's CNES and the Indian Space Research Organization signed a cooperative agreement in January to develop reusable launch vehicles.

After its September 2016 launch pad explosion, SpaceX's Falcon 9 returned to flight in January, achieving 13 consecutive launches, including 10 first/booster stage recoveries as of mid-September. Nine additional launches were scheduled over the remainder of 2017, while Falcon Heavy's first flight was planned for November. Blue Origin's New Glenn, like Falcon 9, features a reusable first/booster stage and is under development for first flight before 2020.

Use of **electric and hybrid electric/chemical propulsion** increased in 2017 and is expected to be incorporated in more than half of new communications satellites by 2020, facilitating more cost-saving dual-launches and greater satellite capacities.

For new technologies and systems, Space Systems Loral established Space Infrastructure Services to commercialize its on-orbit satellite servicing capabilities and in June announced SES as its first customer. The Chinese announced in June that they set a record demonstrating quantum entanglement encrypted satellite communications.

Three companies — Swiss startup Astrocast, Israeli startup Sky and Space Global, and Amsterdam-based Magnitude Space — each plan to use between 18 and 200 cubesats to facilitate "internet of things" communications.

Despite these advances, the industry remains challenged with identifying new, emerging markets (e.g., 4K/8K ultra-high-definition over-the-top video, internet of things and 5G communications) for sustained, higher demand as well as developing technologies and systems necessary to meet but not oversupply this increased demand. ★

Contributors: Chris Hoerber and Roger Rusch

Computing advances push manufacturing, design, deep learning

BY RICK KWAN

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

If leadership in advanced design and manufacturing are predicated on high-performance computing, then China is clearly laying the groundwork; it continued to have the two fastest machines. Sunway TaihuLight led the Top500 supercomputer list published in June with a Linpack performance of 93.0 petaflops; the machine is built from 40,960 ShenWei SW26010 multicore computing chips. This was followed by China's Tianhe-2 (Milky Way-2) at 33.9 petaflops, which had been the fastest until June 2016. The third place position goes to Switzerland's Piz Daint, a Cray XC50 at 9.8 petaflops. It was previously held by Titan, a Cray XK7 at Oak Ridge National Laboratory in Tennessee. However, Oak Ridge has begun installation of pre-exascale Summit, a system comprised of IBM Power9 central processing units and NVIDIA Volta graphics process units. It is expected to reach peak performance above 200 petaflops and be available to scientific users in January 2019.

The NVIDIA Volta was announced in May and adds Tensor cores for artificial intelligence and deep learning to NVIDIA's CUDA cores for 3-D graphics and physics simulation. This provides new tools for applications like hazardous asteroid discovery, searching for life on exoplanets, autonomous air taxis and simply enabling image and speech recognition in computer-aided design systems.

The **International Space Station acquired its own supercomputer** in August when a SpaceX Dragon capsule delivered a pair of standard Linux-based HP Enterprise Apollo 40 machines as part of NASA's Spaceborne Computer experiment. The machines will provide over a teraflop of computing, an order of magnitude more than was previously available to the ISS. During high-radiation events, power and speed will be reduced to see if the machines continue to operate correctly, without housing them in bulky protective shielding. The machines use Haswell/Broadwell-class general purpose processors.

For its High Performance Spaceflight Computing effort, NASA issued a \$26.6 million contract to Boeing in March to produce prototype chiplet devices. The chiplets will have eight general purpose ARM Cortex-A53 cores in a dual quad-

core configuration and exploit radiation-hard by design techniques. They will support both real-time operating systems and Unix/Linux-based multiprocessing. They are intended for future deep space robotic missions, high redundancy on human missions and high bandwidth sensor data processing for U.S. Air Force missions.

In August, BAE Systems announced availability of its RAD5545 single board computer, which replaces multiple cards used in earlier spacecraft and improves computational throughput, storage and bandwidth. This is intended to enable mission needs such as encryption, multiple operating systems, ultra-high resolution image processing and more. The **RAD5545 SBC provides a 10-times performance increase** over the company's RAD750 SBC, which is found anywhere from Earth orbit to the surface of Mars. It is built using the ANSI/VITA 78.00 SpaceVPX form factor, a flexible, scalable and interoperable standard for high performance space electronics modules.

Early space processor designs have been showing remarkable resilience. The Cassini spacecraft, which plunged into the Saturnian atmosphere in September, carried seven GVSC MIL-STD-1750A computers, designed around 1990 using technology developed in the Department of Defense's Very High Speed Integrated Circuit program a decade earlier. Each processor was capable of 3 million instructions per second. The Cassini spacecraft was launched 20 years ago.

Voyager 1 and 2, launched 40 years ago, have begun exploring interstellar space. They each have three kinds of computers with a total of 32,000 words (16 or 18 bits per word) per computer, running about 8,000 instructions per second. The spacecraft are still alive but on reduced power diets. The radioisotope thermoelectric generators feeding them have a half-life of 88 years. At their distances, they are transmitting 160 bits per second to the Deep Space Network. ★

Contributors: Joe Marshall, Stan Posey

▼ **NVIDIA** unveiled the Tesla V100 with Volta GV100 GPU in May.



NVIDIA



▲ A UL-39 ultralight jet propelled by a ducted fan with a piston engine with a precise altitude difference measurement system test the suitability of systems for installation on unmanned aircraft.

Standards group releases UAS publications

BY EMMANUEL LETSU-DAKE AND PAVEL PACES

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

This was a year of progress for unmanned aircraft avionics, due in part to actions of RTCA, the standards association founded in 1935 as the Radio Technical Commission for Aeronautics. Special Committee 228, which focuses on **Minimum Operational Performance Standards for Unmanned Aircraft Systems**, in May published two related documents. The first, “Detect and Avoid Minimum Operational Performance Standards Phase 1,” designated DO-365, addresses the FAA requirement for “see and avoid.” The standard defines the necessary self-reporting for a UAS, as well as when to provide the pilot in command with the information needed to take corrective action.

Validation of performance requirements for DO-365 was supported by the Integrated Flight Test Series 4 in 2016 involving NASA’s Ikhana unmanned aircraft. Various types of intruder aircraft were used, including King Airs, a T-34, a Gulfstream 3 for high-speed encounters and a TG-14 slow, low-radar cross section.

DO-365 and a second document, “Minimum Operational Performance Standards for Air-to-Air

Radar Detect and Avoid Systems Phase 1,” join DO-362 “Command and Control Data Link Minimum Operational Performance Standards (Terrestrial)” published in September 2016. Together, these documents represent the world’s first set of standards that the FAA will invoke for UAS integration into the U.S. National Airspace System.

A team from the Czech Technical University in Prague in February began **integrating a precise synthetic vision system into a ducted fan UL-39 ultralight jet** with a precise altitude difference measurement system. The goal is to test the suitability of these systems for installation on unmanned aircraft. This altitude determination system improves long-term stability of the microelectromechanical system, or MEMS, sensors for airplane orientation mea-

surements. The system also uses a new method of determining position angles based on precise determination of the pressure differences in areas of the airplane. This is a new kind of information for data fusion within navigation algorithms. In early 2017, the team received altitude data from a stratospheric balloon equipped with the altitude measurement system. The balloon was flown under the European Space Agency’s Balloon Experiments for University Students, or BREXUS, program.

In 2016, a flight of the altitude system was conducted on a general aviation aircraft and, in 2015, on an unmanned aircraft. The pressure difference measurement system evaluated in the flight tests provides altitude differences was found to work perfectly in static conditions in which the altitude difference can be measured with precision of plus or minus 10 centimeters. This result is important for the terrain-mapping technologies in which the vertical difference provided by GPS is not precise enough. However, wind gusts and temperatures degrade measurement and require further investigation. The findings provide a novel way for terrain mapping that requires precise measurements of small vertical differences. The same technology was used for orientation measurement onboard different flying vehicles. These testbeds were used: a laboratory setup, a small UAV with 2-meter wingspan, a general aviation airplane and a stratospheric balloon. ★

Contributor: Erik Theunissen
Pavel Paces teaches at the Czech Technical University in Prague.

Autonomous drone test opens up possibility of low-level urban flights

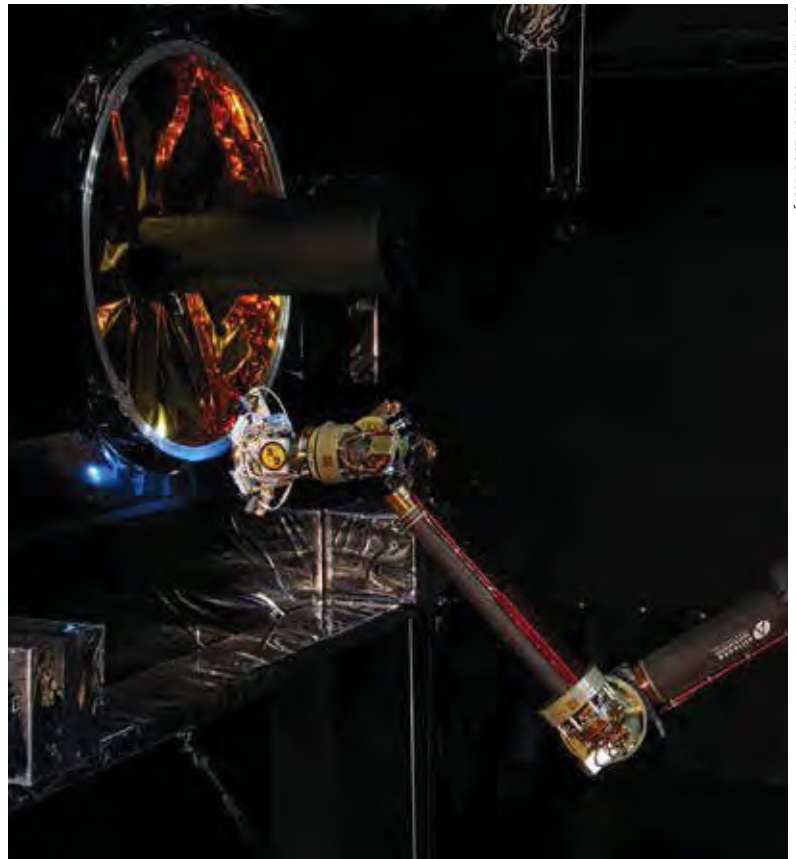
BY NATASHA NEOGI

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

The Institute of Flight Systems at the German Aerospace Center, or DLR, accomplished safe and high-performance flight testing of its hardware and software package that enables low-level autonomous drone flight for urban environment scenarios. The June flight test in Rosenkrug, Germany, required stringent safety considerations due to the close proximity of obstacles and high velocities flown. The benefits of DLR's sensor fusion and mission re-planning approach come from a high rate of environment data fusion and obstacle classification combined with DLR's unique multiquery kinematic path re-planning. The package was retrofitted aboard an 85-kilogram SDO 50 V2 SwissDrones-based rotorcraft with a superARTIS autopilot.

Significant advances were made in human-autonomy teaming in 2017. In February, Aurora Flight Sciences performed a **flight demonstration and at-altitude landing of the Aircrew Labor In-Cockpit Automation System** in a Diamond DA42 aircraft. ALIAS acts as a pilot's assistant, capable of operating an aircraft from takeoff to landing, including contingencies. Developed with DARPA funding, ALIAS is designed to ultimately enable reduced crew operations. In the past two years, Aurora Flight Sciences developed, integrated and tested instantiations of ALIAS in five aircraft. ALIAS is configured to fly a particular aircraft through an offline knowledge acquisition process that rapidly trains ALIAS to be transitioned to new types of cockpits. The core and user interface systems were developed to be vehicle-agnostic, incorporating open architecture principles to easily integrate different types of actuation or perception solutions as well as third-party applications.

Flight tests of an upset recovery guidance system were conducted in April. The system was developed under Small Business Innovative Research contracts with Barron Associates Inc. and Systems Technology and tested by Calspan on its variable-stability Learjet 25B aircraft. This work, sponsored by NASA's Langley Research Center's



U.S. Naval Research Laboratory

▲ The Front-end Robotics

Enabling Near-term Demonstration, or FRENDA, robotic arm is designed to service satellites in geosynchronous orbit.

Vehicle Systems Safety Technologies Project, was led by Christine Belcastro. The system provides pop-up recovery guidance cues to pilots on the primary flight display when an upset condition is detected and is effective for nominal and impaired aircraft. The system improved the recovery proficiency of pilots in all tested scenarios and often reduced over-controlling and oscillations.

Space-related gains in intelligent systems were seen in 2017. DARPA announced in February that it would join with Space Systems Loral on the **Robotic Servicing of Geosynchronous Satellites program**. The RSGS program builds on a decade of work by DARPA and U.S. Naval Research Laboratory, along with efforts from university researchers and space agencies around the world. The project aims to develop a robotic servicing spacecraft that can work on satellites that were never designed to be serviced. The RSGS project is slated for launch in the early 2020s. NASA's Restore-L project, which proposes to refuel and relocate a satellite in low Earth orbit, is on a similar schedule. If successful, these two missions will push the limits of automation and robotic operation in space. ★

Contributors: Jessica Duda, Alexander Stimpson, Florian Adolf, Christine Belcastro and Glenn Henshaw

Push for shared standards on military platforms

BY KENT R. ENGBRETSON AND
THOMAS L. FREY JR.

The **Sensor Systems and Information Fusion Technical Committee** advances technology for sensing phenomena and for combining the resulting data for display to users.

Flexibility was a resounding theme for the year in sensor systems and information fusion as military fixed-wing, rotary and unmanned aircraft all rely on navigation, communications and situational awareness but don't share standards for that software. The U.S. 2017 National Defense Authorization Act included provisions to change that by calling for modular open systems architectures in major platforms, components and interfaces, and U.S. Department of Defense technical directives instruct to expand such open systems architecture standards wherever feasible and cost effective. This would break with the common practice of the Defense Department paying repeatedly for the same functions on different types of aircraft.

Two open systems architectures commonly used by defense aircraft are the Open Group Future Airborne Capability Environment and Open Mission Systems.

The Open Group Future Airborne Capability Environment Consortium, or FACE, has defined an **open systems architecture standard for all military aircraft types and a conformance program to verify compliance**. In March, Rockwell Collins and Harris Corp. were announced as the first companies with software products verified as FACE compliant. Software products developed by the U.S. Army Aviation and Missile Research Development and Engineering Center and Wind River also completed the FACE verification process.

In April, Lockheed Martin partnered with the U.S. Air Force Research Laboratory, the U.S. Air Force Test Pilot School and Calspan for the **Have Raider II program** to demonstrate the benefits of manned and unmanned aircraft working together to improve combat efficiency and effectiveness. Lockheed Martin used the Air Force Open Mission Systems architecture to quickly integrate aviation software from multiple providers into an experimental F-16 Fighting Falcon aircraft. The F-16 surrogate acted as an unmanned combat air vehicle autonomously



U.S. Air Force

reacting to a dynamic threat environment in an air-to-ground strike mission.

The AFRL **AgilePod is a standards-based open source pod engineered to support sensor reconfigurability across multiple aircraft**. Delivered to the AFRL Materials and Manufacturing Directorate by Maryland-based contractor KeyW Corp. in December 2016, the AgilePod is intended to increase the affordability and flexibility of intelligence, surveillance and reconnaissance pods with its modular open systems architecture. Leidos in July announced that as part of the project, it completed testing the AgilePod's sensor systems, which included testing eight sensors in five configurations. Leidos planned follow-on flight tests on the MQ-9 Reaper unmanned aircraft for late 2017.

DARPA in June announced a similar effort with its CONverged Collaborative Elements for RF Task Operations, or CONCERTO, program, which it awarded to BAE Systems. The program will develop a single converged radio frequency payload supporting radar, electronic warfare and communications using less space and power than the combination of discrete systems and maximize the use of common apertures. The program is specifically aimed at unmanned aerial systems in which space, weight and power are at a premium. ★

▲ **The U.S. Air Force Research Laboratory's AgilePod** is being flight-tested aboard a Douglas DC-3 aircraft.

Attention on drone safety and data collection

BY ELLA M. ATKINS

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



NASA

▲ **Valkyrie** was designed and built by the Johnson Space Center Engineering Directorate and has become a mascot of sorts for NASA's Space Robotics Challenge.

Software continues to enable increasingly capable and autonomous aerospace systems. Unmanned aerial systems autopilot software has become reliable, and in 2017, focus shifted to the development of user interface and payload support software. Open-source drone interface apps now allow users to virtually joystick from a touch screen; capture and livestream drone video; direct a drone to follow a smartphone or tablet based on GPS or follow a visual target; and identify obstacles from affordable sensors, such as video and sonar.

Counter-drone software and systems have also become an important area of study given incidents such as an October collision between a commercial aircraft and a drone in Canada. **Counter-drone software** must not only detect an intruding drone, but also classify it as sufficiently hostile to “bring down.” New products such as Maryland-based Department 13's Mesmer counter-drone system — which became available in January — are exploiting weaknesses in digital radio links to take control of a drone's computer for safe landing.

Comprehensive in-flight data collection is critical to understand system use patterns and reveal software flaws. Real-time manufacturer access also ensures patches and upgrades can

be effectively installed. Yet, mobile devices also risk user privacy and security invasion. Drone data collection received increased attention for privacy reasons in 2017. In August, a **U.S. Army memo cited “cyber vulnerabilities” as reason for banning DJI products** because the Chinese drone manufacturer uses automatic data collection. While DJI code remains closed-source, tests using network analyzer products such as Wireshark have shown that actual data capture and reporting depends on choice of ground station software as well as the specific drone model.

NASA's UAS Traffic Management continued to make progress in 2017 with a series of network-enabled tests in which UTM checked drone flight plans for conflicts, approved or rejected each plan, and notified users of constraints. UTM aims to collect systemwide data to enable beyond-line-of-sight flight capabilities as well as to provide weather and traffic data as soon as safety-critical network and software systems can be verified and validated.

Commercial passenger aircraft companies have also adopted new fleetwide data collection software products. In January, Boeing announced a new data analytics global services unit in partnership with Microsoft's Azure cloud platform to provide a variety of services, such as real-time information about atmospheric conditions. In June, Airbus and partner California-based Palantir Technologies announced the release of data platform Skywise to provide an industrywide access point for secure cloud airline operational data. This data can also be analyzed to optimize each aircraft's performance, track maintenance, and to improve operational efficiency and reliability. Announcing a new Asian Customer Care Center in April, Sikorsky is using advanced analytics to better **predict and resolve potential issues before they cause flight groundings or safety issues**. Data analytics products uncover patterns in aircraft performance and parts that can help improve flight safety, optimize aircraft operations and significantly reduce costs.

In the space sector, the NASA Space Robotics Challenge finals were in August. The competition required each team to program a virtual R5 robot to autonomously repair habitat damage caused by a Martian dust storm. The winning team, Co-ordinated Robotics of Newbury Park, California, deployed a virtual R5 (the NASA Johnson Space Center's Valkyrie) that completed all competition tasks using technology augmented from the earlier DARPA virtual robotics challenge. ★

Contributors: James Paunicka and Stephen Blanchette



NASA

new plutonium-238 for use in radioisotope power systems. Sufficient targets were irradiated this year to conduct the next chemical separation demonstration. This separation campaign will emulate a full-production batch size, predicted to lead to about 300 grams of heat-source plutonium oxide. In addition, the DOE has transitioned to a constant rate production strategy to produce 10-15 fueled clads each year. This will reduce plutonium-238 production and NASA mission risks with a steady production and ready supply of heat sources for RPS-enabled missions. This constant rate production approach has the added benefit of reducing the cost to missions using an RPS by approximately 25 percent over the prior mission-fueling surge campaign model.

Voyagers hit 40 years operating, Cassini mission ends

BY BARBARA MCKISSOCK AND GREGORY CARR

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.

▲ **Cassini**, in an artist's rendering, ended its mission with an intentional dive into Saturn's atmosphere.

This year marked the 40th anniversary of the Voyager spacecraft launches. Voyager 1 launched Sept. 5, 1977, and Voyager 2 launched Aug. 20, 1977. Voyager 2 was the first (and only) spacecraft to visit all four gas giant planets (Jupiter, Saturn, Uranus and Neptune). Voyager 1 visited Jupiter and Saturn prior to the Voyager 2 flybys. The Voyager mission was enabled by nuclear power, specifically radioisotope thermoelectric generators. The original requirement for each of the three Voyager multi-hundred-watt RTGs was to provide 128 watts of electricity four years after launch for the originally planned Jupiter and Saturn flybys. They have more than exceeded that four-year requirement, enabling Voyager 2 to be the first spacecraft to fly by Uranus and Neptune and Voyager 1 to be the first spacecraft to fully enter interstellar space.

On Sept. 15, NASA's Cassini spacecraft entered the atmosphere of Saturn after having spent almost 20 years in space and 13 years orbiting the ringed planet. The electrical power provided by three general-purpose heat source RTGs made Cassini's mission possible.

The U.S. Department of Energy, on NASA's behalf, continued to progress on the production of

In July, NASA completed an RPS system study that provided guidance toward future technology investments in modular deep-space thermoelectric generators scaled to notionally produce 50-470 W of power. Based on continued mission need, NASA also initiated four technology development contracts for dynamic energy conversion research.

Preliminary testing of the Kilopower (a small fission reactor power system for space missions needing 1-10 kilowatts electric) nuclear technology demonstration assembly using an electrically heated depleted reactor core simulator was conducted at NASA's Glenn Research Center in Ohio in January. The full Kilopower demonstration features a 4 kilowatt thermal uranium-molybdenum reactor core, sodium heat pipes for heat transfer and Stirling power converters developed during the Advanced Stirling Radioisotope Generator program. A highly enriched uranium core was fabricated in July in three sections at the DOE's Y-12 National Security Complex in Oak Ridge, Tennessee, for shipping to the DOE Nevada National Security Site's National Criticality Experiment Research Center, where it will be integrated into the heat pipe. Power conversion assembly will be tested at Glenn. The demonstration is a partnership between NASA and the DOE National Nuclear Security Administration.

On Jan. 13, astronauts completed installation of lithium-ion batteries on two of the eight power channels on the International Space Station, replacing the old nickel-hydrogen battery technology on the S4 truss. The old batteries were sent to the ISS in early 2007 and were approaching the end of their design life. ★

Electric rockets power bigger share

BY WENSHENG HUANG

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

For the electric propulsion community, 2017 marked a year in which electric rockets steadily became more mainstream.

In June, NASA's Dawn spacecraft completed a one-year extended mission around the dwarf planet Ceres. The mission was enabled by **Dawn's ion propulsion system**. The system has operated for a record-breaking 50,600-plus hours and provided 11.3 kilometers per second delta-v.

Eight colloid micro-Newton thrusters — developed by Massachusetts-based Busek Co. with support from NASA's Jet Propulsion Laboratory in California — flew on the European Space Agency's Laser Interferometer Space Antenna Pathfinder spacecraft and met all mission requirements. These thrusters are the first to demonstrate control of a spacecraft to within 10 nanometer per square root of hertz of positioning noise.

The **Israeli-French Vegetation and Environment monitoring on a New Micro-Satellite**, or VEN μ S, which uses two IHET-300 Hall thrusters from Rafael, was launched Aug 2. Each thruster operates at powers between 300 and 600 watts. This system will perform orbit transfer, orbit maintenance and fine pointing of instruments.

Early in 2017, the Chinese tested two high-throughput Hall thrusters aboard the Shijian-17 satellite. The two thrusters were the Harbin Institute of Technology's 1.5-kilowatt HEP-100MF and the Lanzhou Institute of Physics' 1.35-kW LHT-100.

On May 5, India's Space Research Organization launched its first satellite equipped with electric propulsion. The GSat-9 uses the Russian KM-45 Hall thruster by Keldysh Research Center for station keeping.

Boeing launched its fifth all-electric satellite May 18 and Airbus Defense and Space launched its first June 1. With 20 all-electric communication satellites now on order, the share of all-electric is approaching a quarter of the communication satellite market. The power level of electric propulsion devices that have been used on-orbit now range from about 10 W to 4.5 kW.

Back on Earth, NASA and Aerojet Rocketdyne's Advanced Electric Propulsion System, or AEPS, a 14-kW Hall thruster system, completed preliminary design review in August. Throughout

the year, NASA's Glenn Research Center in Ohio and JPL performed wear testing, accelerated deposition testing, discharge channel material testing, environmental testing and component life modeling. NASA developed a reference human exploration architecture that includes a 50-kW Power and Propulsion Element, which will use the AEPS propulsion string.

Aerojet Rocketdyne, with Ohio-based subcontractor ZIN Technologies, in April completed fabrication of prototype NEXT-C gridded ion thruster and power processing unit. Development testing occurred throughout the year with critical design review scheduled for 2018. One thruster and PPU are reserved for the Double Asteroid Redirection Test mission scheduled for launch in 2020.

In January, NASA's Discovery program selected **the Psyche mission to explore a 200-kilometer metal asteroid** thought to be a destroyed proto-planet core. The mission is scheduled to launch in 2022 and will use an SPT-140 Hall thruster system on a spacecraft jointly built by JPL and Space Systems Loral.

Busek's iodine-fueled BIT-3 RF ion thruster system completed critical design review in June. BIT-3 will provide propulsion for Lunar IceCube, a secondary payload on the Space Launch System Exploration Mission-1. Additionally, a Busek iodine-fueled BHT-600 Hall thruster system began long-duration testing in July at Glenn.

In August at Glenn, a team including the University of Michigan, Aerojet Rocketdyne and JPL tested the **NextSTEP X3 Nested Hall Thruster to a power level of 100 kW**. This represented the first time a Hall thruster had been operated at discharge current above 100 amperes.

In June, Boeing selected the PPS 5000 5-kW Hall thruster for commercial satellite applications. Qualification testing of the PPS 5000 5-kW Hall thruster had been proceeding smoothly at Safran. Also in 2017, the first flight sets of PPS 1350 1.5-kW Hall thrusters were delivered to SSL.

With these projects and more, a revolution in how spacecraft makers and mission planners utilize electric propulsion is steadily gaining momentum. ★



NASA

▲ The X3 Nested Hall Thruster is mounted to a specially made thrust stand at NASA's Glenn Research Center. It was tested to a power level of 100 kW.

Advances in cubesat propulsion, launch technology

BY STEVE NELSON AND STEPHANIE SAWHILL

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.



Pacific Scientific EMC

▲ **The PacSci EMC Satellite** sits ready for installation into its launcher. The payload appears at the top consisting of four solid propellant rocket motors, four pyrotechnic initiators, and a primary and redundant, precision, networked electronic pyrotechnic sequencing system.

The PacSci EMC satellite arrived in orbit in June, carrying the Smart Telemetry and Release System, or STARS, consisting of electronic controller cards, firmware and a communications interface. STARS precisely sequenced the firing of four pyrotechnic devices and four solid propellant rocket motors, called the Modular Architecture Propulsion System or MAPS. The motors were fired in pairs by STARS as commanded from a ground station in Irvine, California. PacSciSat's velocity and altitude were changed by the significant and precise amounts predicted.

Together, STARS and MAPS occupied one 10-centimeter cube of the three-unit PacSciSat cubesat. The remaining units were dedicated to hardware for power, communications, and guidance, navigation and control.

Today's cubesats typically lack propulsion. PacSci EMC, of Arizona and California, which developed the technologies on the PacSciSat, is one of the companies trying to solve this problem.

Incorporating STARS and MAPS into the designs of future cubesats would extend the orbital lives and enable decommissioning and deorbiting of future cubesats.

In the future, STARS could fire tens to hundreds of devices connected by a low power electronic bus. Applications would include deploying satellites and solar arrays.

In the area of launch technology, NASA in June announced the selection of Dynetics of Huntsville, Alabama, to develop and build the Universal Stage Adapter that will carry payloads and connect NASA's Orion spacecraft and service module to the forthcoming Space Launch System rocket. Dynetics then awarded a contract to Systema Technologies of Kirkland, Washington, to build the adapter's Separation Joint System consisting of two rings bolted together and an energetic separation mechanism. One side of this ring assembly will hold the Exploration Upper Stage and the other will hold the adapter with Orion and its service module. This system will bear the structural loads between the upper stage and Orion. In orbit, a solid propellant will burn to generate pressure to break and separate the two rings and release the upper stage from the adapter and deploy the payloads.

The Systema Separation Joint System includes the Low Shock Separation or LS3 technology. Overall, the system applies heritage and known energetics and mechanisms in an innovative way to create one of the largest spacecraft separation systems.

In the research realm, Systema in February demonstrated one of the world's largest pyrotechnic devices when a cable cutter severed a braided steel cable measuring about 13 centimeters in diameter. An oil and gas company is planning to use this cable cutter in place of higher-risk systems to effectively and safely decommission offshore installations. Future applications may be found in the defense and aerospace industries. Pyrotechnic cutters of various configurations are used on launch vehicles, missiles, and parachute deployment and payload release systems. ★

Contributors: Peter Current, Steve Stadler, Hunter Golden

Steve Nelson is vice president for the commercial product line at Pacific Scientific EMC; Stephanie Sawhill is director of business development at Systema Technologies; Peter Current is the technical lead at Pacific Scientific EMC; Steve Stadler is a mechanical engineer at Pacific Scientific EMC; Hunter Golden is chief engineer for missile and space systems at Systema Technologies.



GE Aviation

Certifications show gas turbine engine progress

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.

Certification of many new engines in 2017 showed that gas turbine engine technology is advancing at a rapid pace.

Michigan-based Williams International announced in May that its FJ44-4A-QPM engine was selected by Swiss aircraft manufacturer Pilatus for its PC-24 business jet. The FAA and European Aviation Safety Agency certified the engine, which led to the announcement. Williams included many new technologies, including a quiet power mode that provides efficient ground power and eliminates the traditional auxiliary power unit.

One Aviation Corp., headquartered in New Mexico, announced in June that the Williams FJ33-5A-12 turbofan engine will power the new EA700 “Project Canada,” an improved version of the Eclipse 500/550 aircraft. The FJ33-5A-12 will allow the EA700 to exceed performance goals, with a maximum range in excess of 2,700 kilometers and the ability to climb direct to its maximum altitude even on hot days.

Rolls-Royce, based in the Britain, marked a milestone for the **Trent 1000 TEN engine** in March, powering the first test flight of the Boeing 787-10 Dreamliner aircraft. The Trent 1000 TEN will contribute to the Dreamliner halving the noise footprint of previous-generation aircraft. EASA granted full flight certification in August while Rolls-Royce delivered the first passenger engines to Boeing in Washington.

Rolls-Royce started power runs of the world’s most powerful aerospace gearbox in May in

▲ **A GE9X engine** underwent a series of preliminary natural-icing tests at the Peebles Test Operation in Ohio.

Germany. The gearbox enables larger fan sizes and reduces weight. Rolls-Royce achieved a record-setting 70,000 horsepower and plans to reach 100,000 horsepower — the equivalent of more than 100 Formula 1 cars.

GE began certification testing of its **GE9X engine** at the Peebles Test Operation in Ohio in May. The GE9X will power Boeing’s new 777X aircraft. To prepare for the certification program, GE commenced trials in March 2016 and concluded this year with icing tests. GE has slated the GE9X for installation and flight tests aboard GE’s 747-400 Flying Test Bed in California.

Mitsubishi Heavy Industries, Mitsubishi Aircraft and Pratt & Whitney announced in May that Pratt’s PW1200G geared turbofan engine was type certified by the FAA and will power the MRJ-70 and MRJ-90 aircraft. The engine and the aircraft wing and aerodynamics were designed in a collaborative program to create a next-generation regional aircraft. The engine’s advanced technology will contribute to a 10-20 percent reduction in operating costs and 50 percent lower emissions. The FAA also granted **Pratt’s PW1900G engine certification** in May after 18 months of testing, including sea level and operability and performance testing. The PW1900G powers the Embraer E195-E2, which made its first flight in March.

The **Steady Thermal Aero Research Turbine Lab** at the Pennsylvania State University completed facility upgrades in March to enable more realistic turbine test conditions. START studies aerodynamics and heat transfer in turbines at continuous, engine-relevant Mach and Reynolds numbers. The upgrades enable accurate turbine heat transfer measurements through heated flow, full-length airfoils and independently controlled feeds for cooling air. START also employs additive manufactured vanes to place pressure taps and other instrumentation routing in previously unreachable locations, enabling unique measurements of seal effectiveness.

The National Jet Fuels Combustion Program made progress evaluating the suitability of **alternative aviation fuels**, saving time and resources by identifying fuels that will not pass certification processes. Universities perform research activities, and the FAA, NASA and the Air Force Research Laboratory provide funding. The program transitions key scientific approaches from basic research and other combustion programs to develop generic test and modeling capabilities, identify the impact of fuel properties on combustion, and accelerate alternative aviation fuel certification. ★

Contributors: John Sordyl, Daniel Jensen, Aspi Wadia, Karen Thole and David Blunck

Simulation and ground testing mark progress

BY HOWARD "GREG" JOHNSTON AND
LESLIE SMITH

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.

Interest in the science and engineering of high-speed air-breathing propulsion systems is surging across the globe. Strides have been made in areas of aerodynamics, thermal management, materials development and improved flight efficiency through both simulation and ground testing. Various international research teams are exploring multiple ways to develop ground test methodologies, ground-flight correlations and specific trajectory optimization.

At the Arc-Heated Scramjet Test Facility at NASA's Langley Research Center in Virginia in April, several classes of **high-speed fuel injector concepts for scramjet applications** were investigated using planar laser-induced fluorescence. The resulting, high-quality, non-intrusive, experimental data provided insight about mixing and allowed the validation of computational fluid dynamics models used in the analytical studies.

The U.S. Department of Defense's **desire to field hypersonic vehicles powered by air-breathing propulsion systems** has resulted in the need for an analysis-driven knowledge base with an applied engineering focus. The Aerospace Systems Directorate of the Air Force Research Laboratory at Wright-Patterson Air Force Base in Ohio has been working to extend the state-of-the-art beyond the X-51A Scramjet Engine Demonstrator since its last flight in 2013. Throughout 2017, AFRL has been preparing direct-connect testing of two unique powerhead concepts through the Medium Scale Critical Components program in the Aerodynamic and Propulsion Test Unit at the Arnold Engineering Development Complex in Tennessee. The two engine test articles have an air mass capture approximately 10 times that of the X-51A engine and employ common isolator and combustor components. Flow characterization through the facility nozzle and distortion generator at the simulated M=4 flight condition was completed in May. Initial engine tests were expected in late 2017.

AFRL also made significant strides throughout the year in developing and using advanced high-frequency optical diagnostic techniques to

elucidate the fundamental physics involved in supersonic reactive flows. Researchers used simultaneous schlieren, chemiluminescence and hydroxide planar laser-induced fluorescence for the same field of view at bandwidths of 40 kilohertz in studies of the ignition process of a cavity-based flame holder in supersonic flow. The spatially and temporally resolved measurements provide an unprecedented perspective of the starting transients that each diagnostic alone cannot achieve.

The German Aerospace Center, or DLR, has conducted tests throughout the year in Lampoldshausen that **characterized the interaction between wedge flame-holders at test bench M11.1**. Investigation of high-speed transpiration cooling systems for scramjets has been ongoing since 2014, with earlier work in 2000 on rocket combustion chambers. In September, DLR researchers carried out cold air tests on a variable geometry inlet for operation from Mach 3.0 to Mach 4.5 in DLR's trisonic wind tunnel.

The National Natural Science Foundation of China funded an eight-year research project valued at \$23 million to foster technology, multi-disciplinary optimization and integrate hypersonic technology for a near-space maneuverable vehicle. China's turbo-aided rocket-augmented ram/scramjet combined cycle engine, or TRRE, was set for free-jet testing at the end of 2017.

Russia's Central Aerohydrodynamic Institute, or TsAGI, and its Central Institute of Aviation Motors, or CIAM, designed and performed direct-connect and aerodynamic testing in their facilities on a civil hydrogen powered-vehicle concept program in T-131 and C-16VK wind tunnels, respectively, demonstrating positive net thrust at Mach 7. Testing began in 2014; the last tunnel entry was in August. ★

Contributors: Kevin R. Jackson, Dean R. Eklund, Timothy M. Ombrello, J. Philip Drummond, Erik Axdahl, Johan Stellant, Venkat Tangirala, Ali Gülhan, Friedolin Strauss and Dvoynikov Alexander

▼ **This variable high-speed inlet** was developed by DLR, the German Aerospace Center.



DLR

Hybrid rockets: To wax or to whirl?

BY JOSEPH MAJDALANI AND ORIE M. CECIL

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

Hybrid rocket technology advanced on several fronts in 2017, from winning a first-ever sounding-rocket competition to developing new combustion techniques and additively manufacturing propellants.

Development of a **space-storable hybrid motor for a Mars Ascent Vehicle**, part of the proposed Mars Sample Return mission, also made progress. Studies led by the NASA-funded Jet Propulsion Laboratory determined that a storable, single-stage-to-orbit, hybrid propulsion system may be the lowest mass option for an ascent vehicle. Efforts are underway in hybrid grain production, full-scale testing and hypergolic additive investigations to support the launch of an Earth-based demonstrator in 2019-2020.

This past year, NASA's Marshall Space Center established the capability to produce a monolithic wax-based fuel grain engineered by the Space Propulsion Group. JPL also supported hot-fire testing of this fuel with mixed oxides of nitrogen (nitrogen tetroxide and nitric acid) at both SPG and California-based Whittinghill Aerospace. Additionally, researchers at Purdue and Pennsylvania State universities investigated new solid fuel additives for hypergolic ignition to facilitate in-flight stop/restart capability.

Streamline Automation, KEI, Auburn University and the University of Alabama at Huntsville continued **developing a vortex hybrid rocket engine**. The engine uses cyclonic flow combustion: an outer, annular flowfield spirals up the fuel port walls while an inner, core vortex carries the combustion products through a unique exit nozzle. Oxidizer is injected at the nozzle end, tangentially into the chamber. The centrifugal forces generated by the swirling flow lead to high, axially uniform regression rates and neutral burning, with controllable oxidizer/fuel mixture ratios that can be further optimized through head-end injection.

Vortex combustion also increases the total impulse and fuel loading efficiency by using a circular-port grain and eliminating sliver formation. The reduction of thermal loading on the chamber walls allows use of thinner and lighter materials. The single-port grain and single-cartridge housing max-



Utah State University

imizes volumetric loading efficiency while facilitating cleanup between successive uses. Modeling and simulation by Auburn University to optimize the nozzle and engine port geometry have produced a high-performance engine that is capable of very high regression rates. Numerous tests of a 4-inch, 1,000 pound-force vortex engine were carried out at the University of Alabama at Huntsville demonstrating the feasibility of this concept.

In other developments, scientists at the University of Electro-Communications in Tokyo in March developed a design optimization procedure that can **extend the range of hybrid rockets**. This is based on an extinction-reignition protocol that takes into account flight path stability, duration and range in the thermosphere (80-120 kilometer altitude).

In July, DARPA awarded Florida-based Rocket Crafters a contract to develop a 5,000 pound-force hybrid rocket using its Direct-Digital Advanced Rocket Technology. This uses additive manufacturing to directly print fuel grains and combustion chambers simultaneously using high-energy polymers.

Utah State University tested a novel **hybrid thruster that employs medium-grade hydrogen peroxide** (80-85 percent) and additively manufactured acrylonitrile-butadiene-styrene as the primary propellants. This operates with a low-grade agricultural oxidizer by preceding the peroxide flow into the thrust chamber with a short burst of gaseous oxygen. An arc-ignition system then ignites the ABS propellant in the oxygen flow, with the peroxide flow starting immediately upon ignition. Thrust levels between 180 and 205 newtons were achieved from multiple on-demand restarts, and specific impulse levels exceeding 215 seconds were reported.

In June, the first Spaceport America Cup was at New Mexico's Spaceport in partnership with the Experimental Sounding Rocket Association. Out of 110 teams competing to launch a 4-kilogram payload to either 10,000 or 30,000 feet, depending on their choice of propulsion, a student team from the University of Michigan, Ann Arbor, won with a hybrid engine that enabled them to exceed the 30,000 foot goal. ★

▲ **Utah State University** tested a hybrid thruster that employs medium-grade hydrogen peroxide and additively manufactured acrylonitrile-butadiene-styrene as the primary propellants.

Boundary layer ingestion could help commercial aircraft efficiency

BY NEAL HERRING

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

Boundary layer ingestion received renewed attention this year as a potential way to significantly reduce drag and increase fuel efficiency of future commercial aircraft.

A major step forward came with the analysis throughout the year of the tests of a **first-of-kind boundary layer ingesting inlet and distortion tolerant fan stage** completed in December 2016 in the transonic test section of the 8-by-6-foot supersonic wind tunnel at NASA's Glenn Research Center in Ohio. The tests were designed to measure the performance and operability of a BLI inlet and fan embedded in the upper surface of a blended wing body aircraft.

The United Technologies Research Center designed the propulsor with input from NASA and Virginia Tech as part of a broader joint research effort led by NASA. The BLI inlet-fan system ingests the lower-velocity airflow over the aircraft's surface into the engine, enabling it to generate the required thrust with less power input. This results in significantly less fuel being burned to accomplish a given aircraft mission. A key challenge in designing a propulsor of this type is the

highly non-uniform flow into the inlet and the structural impact on the rotating fan as its blades move through regions of distorted flow.

To experimentally evaluate the embedded BLI propulsor, an aircraft flow field simulator was designed and constructed between October 2011 and February 2016. The 8-by-6-foot tunnel is the only test facility in the world capable of evaluating embedded BLI propulsors with proper control of the incoming inlet flow. The BLI propulsor was operated from November to December 2016 for a total of 104 hours and produced a large dataset that was analyzed in 2017, including aerodynamic performance, aeromechanical response and many other measurements.

The propulsor exhibited good operating characteristics across the extent of its operating map. Through this effort to address the key challenges to BLI propulsion — integrated inlet-fan design, airflow distortion and aeromechanics including high-cycle fatigue — the door has been opened to further exploration of boundary layer ingesting propulsors for highly efficient subsonic commercial aircraft.

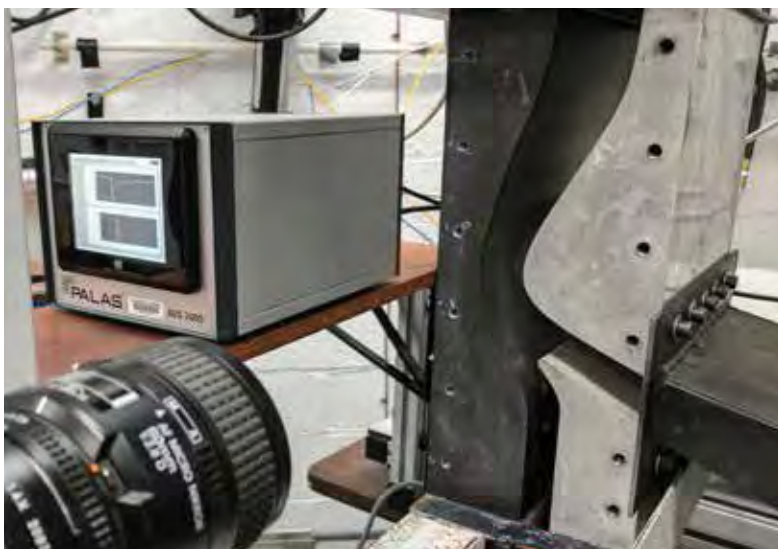
Also in propulsion systems integration, Rolls-Royce hit its seventh year of partnership with the University of Virginia to improve the performance of engine air particle separators, or EAPS, for gas turbine engines operating in austere environments. As presented at the 2017 AIAA Propulsion and Energy Forum in July, an EAPS flow path designed under this partnership completed coarse dust testing. The new flow path allowed unprecedented reductions in system power consumption combined with increased particle removal fraction. Flow visualization and particle image velocimetry revealed complex vortical separation structures related to the combination of flow split and adverse pressure gradient separation.

The EAPS uses minimal engine power to filter out particles that could otherwise damage engine components. This allows aircraft landings at deserts, beaches or anywhere with potential brownout conditions. The flow path is designed with an inner surface shaped so that larger particles will bounce into an outer scavenge region and an outer surface shaped so that smaller particles will be centrifuged to the scavenge region via flow turning.

The partnership added significant computation resources to the project in 2017 to support the experimental efforts. The Rolls-Royce and University of Virginia research team will continue to use bifurcated wind tunnel testing to study particle trajectories in a prototypical flow field that captures the highly unsteady and separated flow field features. ★

Contributors: David Arend, Bill Cousins and Eric Loth

▼ An engine air particle separator flowpath is shown in the test rig at the University of Virginia.





NASA

drone ship in the Atlantic Ocean. The first stage had previously flown in April 2016.

In April 2017 in Redmond, Washington, Aerojet Rocketdyne completed qualification testing of an **MR-104J 440 newton mono-propellant hydrazine thruster** for the Boeing CST-100 Starliner crew module propulsion system.

In Europe, Ariane Group continued development of the propulsion systems for Ariane 6, with the upper stage Vinci and lower stage Vulcain 2.1 engines undergoing qualification testing in March and October, respectively. Also, Prometheus, a low-cost, throttleable methane engine, matured jointly by the Ariane Group and France's

CNES, transitioned into an ESA development program in June.

The Japan Aerospace Exploration Agency continued maturation of **the next Japanese flagship launch system, the H3**. The first test campaign of the LE-9 first stage oxygen/hydrogen expander bleed cycle engine was completed in July at the Tanegashima Space Center test stand, demonstrating engine operations, including start and shutdown transients.

NASA's Satellite Servicing Projects Division conducted **full-scale water tests of the robotic propellant transfer subsystem for the upcoming Restore-L mission** in July. NASA's Space Technology Mission Directorate completed plume characterization tests of Busek's 5 N AF-M315E green monopropellant thruster in June and testing of Aerojet Rocketdyne's heavyweight 1 N thruster at NASA's Glenn Research Center in Ohio.

In facility news, refurbishment of Stennis' B2 test stand for the SLS core stage testing was completed in September. In March, Glenn's In-Space Propulsion Facility at Plum Brook Station in Sandusky, Ohio, completed tests at simulated altitude and thermal conditions of Johnson's Integrated Cryogenic Propulsion Test Article.

A new facility comprising five reinforced test cells at Purdue University's Zucrow Laboratory in West Lafayette, Indiana, was dedicated in September. This facility will facilitate the application of advanced laser diagnostic techniques to combustion zone measurements for rocket and air breathing systems operating at realistic pressures and heat release rates. Its laser laboratory will house numerous diode-pumped solid state laser systems, burst mode lasers and ultrafast laser systems for high-repetition-rate imaging measurements. ★

Progress achieved on liquid propulsion systems for Space Launch System

BY J. ARTHUR SAUER AND VINEET AHUJA

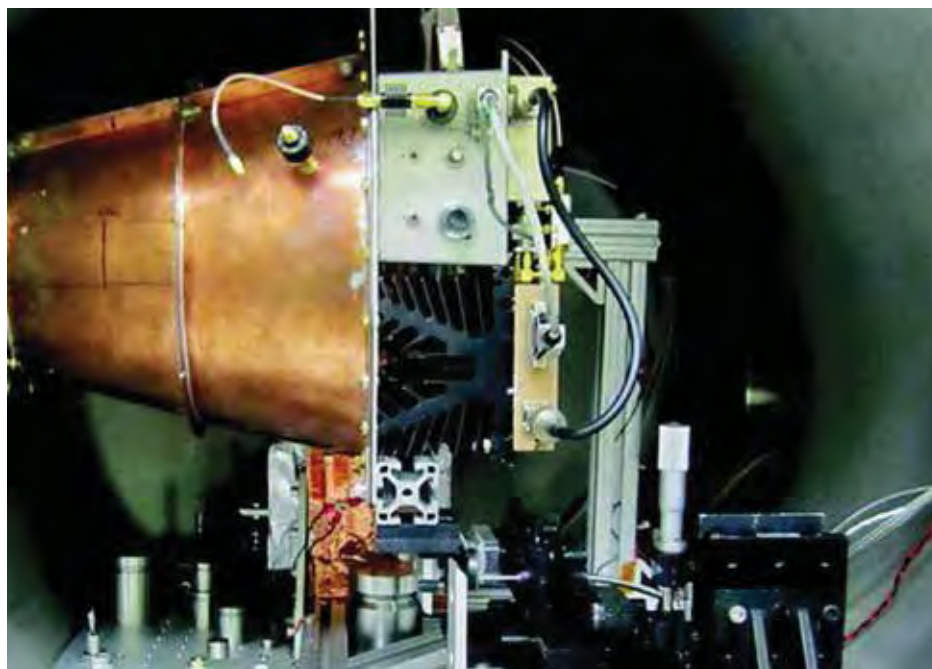
The **Liquid Propulsion Technical Committee** works to advance reaction propulsion engines employing liquid or gaseous propellants.

▲ **NASA's Stennis Space Center** in Mississippi completed refurbishment of the B2 Test Stand in preparation for Space Launch System core stage testing planned for 2018.

In 2017, significant progress was made in preparing the liquid propulsion systems of NASA's Space Launch System for Exploration Mission 1. In October, NASA's Stennis Space Center in Mississippi and Marshall Space Flight Center in Alabama, along with Aerojet Rocketdyne — completed hot-fire tests of space shuttle heritage RS-25 flight units modified for SLS operations, demonstrating the new-design engine control units and full duration mission profiles. In addition, Aerojet Rocketdyne began RL10 integration activities for the SLS Block-1B vehicle exploration upper stage.

Shuttle-heritage **Orbital Maneuvering System engines were acceptance tested** at NASA's Johnson Space Center in Texas and White Sands Test Facility in New Mexico and delivered along with Aerojet Rocketdyne's R-4D-11-derived auxiliary engines to the European Space Agency and Airbus in Bremen, Germany, for integration into the Orion service module.

In commercial launch and crew systems activities, SpaceX achieved a notable milestone in rocket reusability when its Falcon 9 rocket launched a geosynchronous communications satellite in March from NASA's Kennedy Space Center. Following stage separation, the first stage returned to Earth for a second time, landing on a



NASA

Concepts program demonstrated ongoing interest and support for future flight research when it awarded four new Phase 1 and one new Phase 2 research awards supporting advanced propulsion and power technologies.

Princeton Satellite Systems' Phase 2 award supports a direct fusion drive concept that leverages the Princeton Field-Reversed Configuration fusion reactor under development at the Princeton Plasma Physics Laboratory in New Jersey.

For the NIAC Phase 1 awards, two were also for fusion technologies — another novel direct drive concept at NASA's Marshall Space Flight Center in Alabama and a compact fusion power reactor concept at the University of Maryland. Another Phase 1 award went

to NASA's Jet Propulsion Laboratory to support the **development of an advanced power beaming architecture for interstellar precursor missions**, potentially enabling a 12-year flight time to 500 astronomical units. The fourth Phase 1 award was granted to the California-based Space Studies Institute to support investigation into the Mach Effect Gravitational Assist Drive, another somewhat controversial propellantless space drive based on a principle of inertia credited to the physicist and philosopher Ernst Mach. These and other NIAC-funded research projects were presented at the NIAC Symposium in Denver at the end of September.

The NASA Space Technology Research Directorate's Nuclear Thermal Propulsion project (managed at Marshall) progressed. In addition to NASA's ongoing work with Aerojet Rocketdyne, Dynetics and other companies, Virginia-based BWX Technologies in August was awarded a contract to support NTP reactor design, fuel development and other tasks.

Also in August, a **surrogate for the NTP baseline ceramic metal, or cermet, fuel** was tested using NASA's Compact Fuel Element Environmental Tester, taking advantage of features added in a recent CFEET upgrade that allowed for finer control of sample heating rates, more accurate temperature measurement and features to enhance the device's utility. Work toward demonstrating a subscale exhaust capture system at NASA's Stennis Space Center in Mississippi was initiated in June. ★

Contributor: Michael Houts

A banner year for future flight

BY RAYMOND SEDWICK

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

▲ **NASA's EmDrive** experimental setup: Microwaves moving around inside this copper, bucket-shaped test article in Houston appear to have generated thrust toward the article's narrow end, hinting at a potentially propellant-free mode of propulsion.

The year saw advanced propulsion research hit the mainstream with dozens of media articles discussing the EmDrive, or Electro-magnetic Drive, using often inappropriate terms like “warp drive.”

The articles came after news leaked that a research paper on the EmDrive had been accepted for peer-reviewed publication in the July/August edition of the AIAA Journal of Propulsion and Power. Many articles claimed NASA researchers had confirmed the viability of a technology that would rewrite the physics textbooks. In fact, the paper claimed no such thing. Instead, it discussed the experiments the NASA Eagleworks team had conducted in 2016 at Johnson Spaceflight Center in Houston to test for any unexplained thrust that might be produced. Similar research to objectively assess the technology is ongoing at other institutes, such as the Technical University at Dresden in Germany. Researchers continue their efforts to reduce experimental uncertainty and establish an upper-bound on any perceived effect. While it is not possible to prove experimentally that there is no effect at any scale, it is possible to demonstrate that any real effect is below a level at which a practical system could be realized.

In May, the NASA Innovative Advanced



Advances made toward rotating detonation engines

BY STEPHEN HEISTER AND V. TANGIRALA

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.

With the promise of performance gains of 10-15 percent, researchers are advancing the technologies required to make unsteady detonation-based engines a reality for aerospace propulsion and stationary power-generation applications. The rotating detonation engine, or RDE — a device that exploits continuous detonative combustion in a thin annular channel — is the main focus of research, and several critical advances were made in 2017.

Russia's NPO Energomash and Lavrent'ev Institute of Hydrodynamics conducted a long-duration firing of a large-diameter oxygen/kerosene liquid rocket engine with RDE combustion. The U.S. Air Force Research Laboratory in April demonstrated thermally steady operation of an air-breathing RDE with a ceramic matrix composite outer body. In February, AFRL also tested an RDE integrated into a T63 gas turbine as the combustor; results show low nitrogen oxide production and good combustion efficiency, indicating promise for the technology.

The U.S. Department of Energy's National Energy Technology Laboratory continued leading the **implementation of RDE technology into stationary power-generation systems**. Aerojet Rocketdyne planned to conduct hot-fire testing of an air-breathing, natural gas-fueled RDE in November under a \$6 million contract awarded in 2016. And efforts at Purdue University, the universities of Michigan, Alabama and Central Florida, and the Southwest Research Institute complemented the NETL program with advanced measurements and fundamental studies.

▲ **Japanese researchers** developed and tested a 900 N-class oxygen/ethelene rotating detonation engine.

Detonation-based engine research expanded internationally. Japan has a large number of efforts in both RDE and pulse detonation engine technology. In August, a team from Nagoya and Keio universities, the Japan Aerospace Exploration Agency and Muroran Institute of Technology conducted a **330-second specific-impulse, near-vacuum and 895-newton high-thrust experiment with an ethylene/oxygen RDE** with combustion efficiency exceeding 95 percent.

In China, several university groups are working to advance RDE technology. Peking University studied ignition delay time and re-initiation phenomenon. National University of Defense Technology conducted air-breathing RDE experiments and established operability limits. Nanjing Institute of Technology achieved detonative performance in a gasoline-oxygen RDE. Tsinghua University conducted experimental research on RDE combustion instability.

Russia's Semenov Institute of Chemical Physics and Institute of Theoretical and Applied Mechanics focused on a hydrogen-fueled scramjet of significant scale (1.05-meter long and 0.31 m in diameter) demonstrating specific impulse as high as 3,600 seconds in wind tunnel tests over a Mach 4-8 range. Both rotating detonation and longitudinal pulsation modes were observed.

In France, national research center CNRS and the University of Poitiers tested different inner cylinder sizes, while MBDA developed a full-scale RDE for ground tests. ONERA's numerical simulations focused on optimization of injector performance. Warsaw University of Technology studied gaseous methane-oxygen RDE combustors of 150 millimeters and 200 mm outer diameters. The first International Constant Volume and Detonation Combustion Workshop was held in June at ENSMA near Poitiers.

In the U.S., military researchers advanced both rocket and air-breathing RDE technology. The Naval Research Lab studied inlet/combustor interactions in a ramjet RDE operating at 42,000 feet and Mach 2.5. NRL also developed detonation models for fuel blends, quantifying the effect of blending hydrogen with methane through propane on induction times and detonation stability.

The Naval Postgraduate School explored the impact of engine inlet characteristics on the performance of an air-breathing RDE. The investigation involved hot-fire testing with detonation zone imaging, optical diagnostics and collaborative computational efforts with NRL. Purdue tested a high-pressure rocket RDE fed by gas from a liquid oxygen preburner using both natural gas and methane fuels. Operation was demonstrated at pressures exceeding 400 psi. ★

Newest data challenges assumptions and norms

BY AARON W. SKIBA AND TRAVIS R. SIPPEL

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.

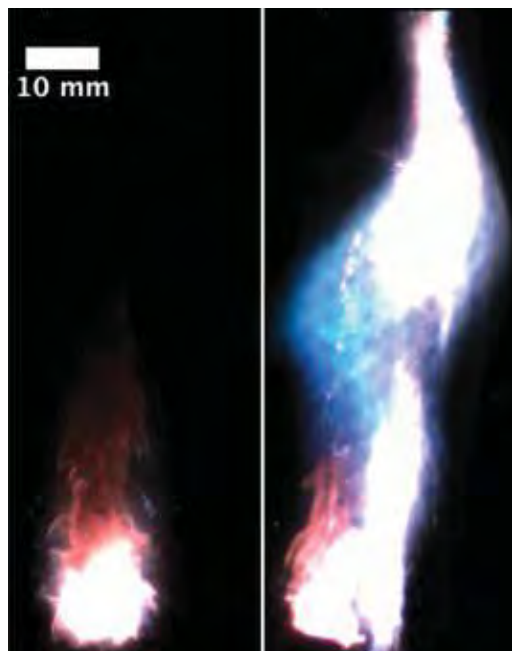
Collaborative efforts between the University of Michigan and the Air Force Research Laboratory at Wright-Patterson Air Force Base in Ohio in 2017 significantly advanced understanding of the effects that extreme turbulence levels have on the structure of premixed flames in gas turbine combustors. Planar laser-induced fluorescence imaging of several chemical species associated with the preheat and reaction layers of premixed flames was employed in January, February and May to elucidate the effects that engine relevant turbulence intensities have on the structure of these layers. Turbulent premixed combustion theories have long suggested that when the turbulent Karlovitz number (Ka_T , defined as the ratio of a characteristic chemical time scale to the smallest turbulent time scale) exceeds a value of 1 and 100 for the preheat and reaction layers, they become broad in comparison to their laminar counterparts.

The significance of these theories is that they are commonly invoked when selecting turbulent combustion models to, say, design a gas turbine engine. However, the results of the 2017 experiments indicate that the classical notions that preheat and reaction layers will broaden or extinguish once Ka_T exceeds 1 and 100, respectively, are incorrect. In fact, **reaction layers of flames with values of Ka_T as large as 530 were found to be continuous and their average thicknesses approximately the same as that of a laminar flame.** It is believed that this work will assist modelers with the selection of the most accurate and robust tools for simulating highly turbulent combustion phenomena, such as those found in modern gas turbine engines.

Also through an ongoing effort, a team led by Travis Sippel and James Michael from Iowa State University and Eric Miklaszewski of the Naval Surface Warfare Center, Crane Division, in 2017 conducted experiments focused on enabling electromagnetic control of energetic materials. In research led by ISU funded by AFOSR Space Propulsion and Power, experiments were conducted to specifically address lack of throttleability in solid rocket motors — and inherent mission flexibili-

ty — afforded by their liquid or hybrid counterparts. This was accomplished by the use of energetic material dopants that allow electromagnetic control of combustion. Using an alkali metal doping technique, ISU researchers have developed a class of composite solid propellants in which microwave energy can be efficiently deposited to the propellant flame front. The technique exploits the high flame temperature of a propellant in order to cause alkali metal dopants (e.g., sodium) to shed electrons, producing a flame environment that will more favorably absorb microwave energy. Results in 2017 demonstrated that **doping enhances flame coupling with low-strength microwave fields and increases burning rate enhancement efficiency.** An increase in burning rate of more than 60 percent has been demonstrated. Studies also conducted in early 2017 demonstrated that with higher field strength, doping may not be required at all and at some field strengths, high-temperature propellant flames enable microwave energy deposition directly to aluminum oxide combustion features.

The concept of using microwave energy to control combustion is also being considered in other areas of energetics. In August 2017, researchers at NSWC Crane, in collaboration with ISU explored the use of microwave energy to dynamically control and enhance the photoemission of pyrotechnic compositions. Many pyrotechnic formulations already contain alkali metals and are attractive candidates for microwave enhancement. The goal of these efforts is to produce a next generation of “smart” pyrotechnics whose brightness and/or color emission can be enhanced and controlled on command. ★



◀ **This is a still image sequence** of a pyrotechnic flame without microwave enhancement (left) and with it. Microwave energy is deposited to the pyrotechnic flame and enhances the light emission volume and brightness of the flame. The color of a microwave-enhanced flame can be controlled by the chemical composition of the energetic material, as microwave energy is deposited to specific combustion species/products present within the flame, resulting, in this case, in blue flame emission.

Naval Surface Warfare Center, Crane Division, Iowa State University

Missile launches, large space boosters register solid performances

BY CLYDE CARR, ROBERT BLACK AND JOSEPH MAJDALANI

The **Solid Rockets Technical Committee** works to advance the art, science and engineering of solid rocket propulsion and to foster dissemination of new knowledge in this field.

Solid rocket motor propulsion achieved notable milestones this year in the U.S. and European defense and space industries. In February, the U.S. Navy launched four unarmed Trident 2 D5 ballistic missiles as part of the Follow-on Commander's Evaluation Test program. Aerojet Rocketdyne and Orbital ATK provided propulsion with integration through Lockheed Martin.

To demonstrate battle readiness of its high-speed defense weaponry, **the Missile Defense Agency flew numerous interceptor systems.** For example, the Aegis SM-3 Block 2A flew in February using Aerojet Rocketdyne boosters and Divert and Attitude Control System, or DACS, to collect performance data. The Ground-based Midcourse Defense interceptor, Orbital ATK's Orbital boost vehicle, tracked and destroyed an intercontinental ballistic missile-class target in May. Similarly, in June, Raytheon's SM-6 Block 1A interceptor completed its final land-based test by destroying a subsonic target in southern New Mexico. In July, the Terminal High Altitude Area Defense system with an Aerojet Rocketdyne booster and DACS intercepted and destroyed an Orbital ATK air-launched target in a real combat scenario over the Pacific.

NASA's **Space Launch System continued testing of its launch abort system.** At Orbital ATK in June, the reduced-thrust abort motor was fired and readied for qualification. The corresponding three-valve Attitude Control Motor HT-11 test in May helped verify new hardware and related analyses. Meanwhile, at Aerojet Rocketdyne, the jettison motor completed its third development test. In emergencies, the launch abort system operates by firing the launch abort motor and attitude control motor followed by the jettison motor to prepare the crew module for a safe landing. In October 2016, Aerojet Rocketdyne also static-tested a Blue Origin crew capsule escape solid rocket motor.

Over the year, six Atlas 5 vehicles, powered by AJ-60A strap-on boosters and Orbital ATK retro separation motors, were launched. The Atlas 5 missions included the Cygnus cargo spacecraft to the International Space Station in April and five



U.S. Army

communications payloads launched into orbit from January through October. Other flights included a Delta 4 with four Orbital ATK Graphite-Epoxy Motor strap-on boosters in March and a Maxus-9 July launch from Sweden using an Orbital ATK Castor 4B first-stage motor. Furthermore, Orbital ATK's all-solid Minotaur 4 and C launch vehicles (Peacekeeper-derived) placed military and commercial satellites into orbit in August and October.

From a tactical perspective, Lockheed Martin delivered the **2,000th Joint Air-to-Surface Standoff Missile** to the Air Force and continued its lethality enhancement flight demonstrations. Aerojet Rocketdyne delivered the 2,500th Patriot Advanced Capability Cost Reduction Initiative tactical missile and the 500,000th PAC-3 attitude control motor used to maneuver the Patriot missile. Aerojet Rocketdyne's Army Tactical Missile System motor propelled Lockheed Martin's long-range surface-to-surface guided ATACMS rocket in six consecutive flight tests from November 2016 through May 2017.

Overseas, the European VEGA launch vehicle saw its 10th operational launch, delivering an Israeli optical satellite and the Venus Earth observation satellite. The VEGA employed three Avio Spazio solid rocket motors: P80, Zefiro 23 and Zefiro 9. The Ariane 5 launch vehicle achieved its 95th flight using two boosters from Europropulsion. In related news, the P120C SRM development for VEGA-C and Ariane 6 launch vehicles continued. The first filament wound case was manufactured and shipped for inert casting in September. The P120C has a 3.4-m outer diameter motor and contains 142 tons of propellant. So far, the ArianeGroup has finalized the nozzle design and manufactured the nozzle parts. The first P120C static firing is expected in March 2018. ★

▲Aerojet Rocketdyne's Army Tactical Missile System motor propelled Lockheed Martin's long-range surface-to-surface guided rocket for a series of tests.

Contributor: *Agostino Neri*

Testing alternative fuels, solar-thermal systems

BY BHUPENDRA KHANDELWAL, JAMES CRONLY AND KEIICHI OKAI

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

The rapid growth of the aerospace sector inevitably has an increasing effect on the environment. For decades, the aircraft propellant we use has almost been taken for granted, and while fit-for-purpose testing has been rigorously applied, the particular composition of jet fuel and its varying performance, based on its inherent characteristics, has only come under scrutiny in the past few decades. Much of the work on alternative and renewable fuels to date stems from the need to avoid compromising safety, operability, overall emission profiles, hardware readiness, cost and reliability as these fuels are introduced.

The Low Carbon Combustion Center at the University of Sheffield, United Kingdom has been working on fit-for-purpose performance testing of alternative and novel fuels for more than a decade. Currently, total aromatic content is directly controlled by fuel standards (including polycyclic aromatic hydrocarbons), but not different aromatic species. The aromatic content of aviation fuels is primarily responsible for the generation of smoke, unburned hydrocarbons and the infrared radiation of the exhaust stream. Increased smoke is usually associated with increased flame radiation, which in turn may reduce hot-end life by increasing surface temperatures and abrasion by carbon particles. Conversely, current systems require the presence of aromatics to ensure system compatibility and energy density. A team at the LCCC is focused on the aromatic species type and its concentration in fuel as a fundamental step toward crafting fuel to optimize performance regarding reduced smoke emissions while preserving system compatibility. In 2017, the LCCC team worked on testing a wide range of aromatics and blends with an aim to find the optimum aromatic type. Results produced by the team in May and June could provide a significant step toward optimizing fuels for the future. Aromatic-free alternative feedstocks and production pathways are now available and require blending with conventional fuels or the addition of synthetic aromatics.

Compared with conventional aviation fuels, renewable jet fuels are intended to be more eco-friendly, which means lower particulate matter,



NEDO

less smoke, less carbon dioxide and less nitrogen oxides will be generated. However, the absence of aromatics or smaller amount of aromatics may cause elastomer seal swell performance issues and compatibility problems in the legacy hardware. For this reason, aromatic content is now fixed at a minimum of 8 percent in synthetic fuel blends to keep fuel within experience norms. However, results produced in 2017 by the LCCC team could lead to steps being taken for even lower aromatic content in the fuel or optimization of aromatic types.

All these benefits could be crucial for future fuels and engines by helping take a big leap toward the development and implementation of improved performance fuels in the future.

In the area of solar and thermal power, Actree Co. Ltd. in Japan, under a grant from the New Energy and Industrial Technology Development Organization, or NEDO, in September started field testing a tracking concentrator type solar energy recovery system that realizes combined solar power generation and solar thermal heat recovery. The system consists of parabolic reflectors arrayed in units consisting of four reflectors by six reflectors. The system is equipped with GPS to direct columns of units toward the sun, resulting in high etendue, or concentration, efficiency. The system efficiency goes up to 65 percent, combining power generation at 25 percent efficiency and heat recovery at 40 percent efficiency.

In the ongoing field testing, eight units generating a total of 13 kilowatts are set up in the head office location, and performance, durability and suitability of a remote control system for maintenance have been tested and validated. On the validation of the remote control system, Softbank Co. Ltd. plans to participate in this testing. This small system, packaged with the remote control system, facilitates efficient utilization of renewable energy in mountainous areas and outlying islands. ★

Contributor: Ryo Amano

Bhupendra Khandelwal leads a combustion and emission team at the Low Carbon Combustion Center in the U.K. that tests alternative fuels and blends.

▲ **This tracking concentrator type solar array**, which is in field testing by Actree Co. Ltd. in Ishikawa Prefecture, Japan, automatically follows the sun across the sky.

Space suits, virtual reality tools tested

BY JONATHAN G. METTS

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

Boeing unveiled a new space suit for its Starliner spacecraft in January, and SpaceX displayed its new space suit for the Dragon V2 in August. Both suits replace the orange one worn on space shuttle flights. These suits are designed to be worn primarily as survival gear during launch and entry, protecting astronauts in case of cabin depressurization, launch aborts or off-nominal landings.

NASA's own Z-2 prototype suit, designed for both microgravity operations and planetary exploration, was tested in March with underwater mock-ups at the Neutral Buoyancy Laboratory in Houston. The aquatic training facility is where NASA's space station crews practice for spacewalks.

► **The Miniature Exercise Device**, or MED-2, was tested by astronauts on the International Space Station in July and September.



Virtual reality has become a powerful new tool in spaceflight ergonomics and crew training. In March, a portable, commercial-grade Oculus headset replaced an older VR rig on the International Space Station. Astronauts in orbit enter a NASA-developed VR simulation to practice maneuvers in microgravity before their real spacewalks.

Back on Earth, the **Active Response Gravity Offload System simulator** (a mechanized hoist to unload a person's weight) at NASA's Johnson Space Center was reconfigured in April for Mars-like gravity and paired with custom VR software to simulate a Mars environment for improved realism in crew training. This type of hands-on, immersive study in a realistic simulation is designed to help engineers develop more effective suits and habitats for Mars surface operations.

Partial gravity was also a focus of investigation this year in basic life science research and

development of countermeasures against long-term spaceflight.

"Sclerostin antibody inhibits skeletal deterioration in mice exposed to partial weight-bearing" was published in February's Life Sciences and Space Research. The rodent research used simulated partial gravity analogs for the moon and Mars to validate a bone loss countermeasure that also works for humans.

Astronauts first tested NASA's **Miniature Exercise Device**, or MED-2, aboard the International Space Station in June. The MED-2 project aims to provide critical exercise countermeasures with reduced mass and volume in smaller spacecraft.

Fire safety and microgravity combustion progressed in June with the third Saffire, or **spacecraft fire experiment**, which ignited a large sheet of flammable material under controlled conditions to study fire growth in an environment without gravity-driven gas convection. The fire was activated far from astronauts in a disposable Cygnus cargo vehicle already on its way toward atmospheric disintegration.

NASA and the space medicine community now recognize **mission-induced vision loss** as a major challenge for long-duration spaceflight. In June, the Journal of Neuro-Ophthalmology published "Persistent Asymmetric Optic Disc Swelling After Long-Duration Space Flight," which compared one astronaut's ophthalmologic data from before, during and after long-term spaceflight to investigate the causes of visual impairment and intracranial pressure syndrome. The subject also received pressure-test-

ing spinal taps in this study on vision impairment during and after months in space.

The Journal of Physiology in February published "Effect of gravity and microgravity on intracranial pressure," which enlisted the help of cancer survivors and measured **the effect of weightlessness on the cranium**. The test subjects were monitored via pre-existing chemotherapy ports in their heads, all while experiencing reduced gravity on parabolic plane flights.

In January, the Orion spacecraft demonstrated crew interfaces during the most dynamic flight phases. The cockpit design was evaluated for visibility and legibility by simulating crew procedures while participants in a mock-up were shaken on the human-rated vibration test bed at Johnson Space Center. ★

Contributors: Richard C. Mains and David L. Urban

ISS lab popular with commercial and government sectors

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.

The International Space Station is increasingly relevant to a broader portion of the science community and commerce, and developments in 2017 bore out this trend.

During ISS Increments 49-51, a team at Chungnam National University in South Korea in March acquired results from the Advanced Colloids Experiment with Temperature Control, or ACE-T1, on the ISS. The ACE-T1 investigated questions about the physics of colloids, which are particles suspended in a liquid. Early results show substantial structural differences between self-assembled clusters formed by using the anisotropic (convex-top) Janus particles (with hydrophilic and hydrophobic ends) in gravity and in microgravity. Advances are important for developing self-assembling, self-moving and self-replicating technologies for potential Earth applications in the areas of self-assembly, photonics, diagnostics and drug-delivery.

The Zero Boil-Off Tank, or ZBOT, experiment was launched to ISS and installed in the Microgravity Sciences Glovebox in 2017. ZBOT explores technology and scientific modeling necessary for future long-duration space exploration missions that require very large cryogenic propellant tanks.

In news that bodes well for the future of ISS research, the National Science Foundation, in conjunction with the Center for the Advancement of Science

in Space, or CASIS, in August awarded \$900,000 in grants to three researchers for zero-gravity combustion research on station. The research could lead to advances in fire protection, combustion engines and biomedical technologies, according to a National Science Foundation press release.

CASIS and the National Center for Advancing Translational Sciences, part of the National Institutes of Health, in June announced five multiyear grants to examine human physiology and diseases onboard the ISS.

As agencies other than NASA put experiments on the ISS, they confirm its practical and desirable character as a research laboratory.

The commercial sector also invested in ISS science in 2017. The Target store chain, working with CASIS, announced in July the “ISS Cotton Sustainability Challenge,” which solicits proposals for biological, remote-sensing, or physical science experiments on ISS to improve the sustainability of commercial cotton crops on Earth. The winning proposal, to be announced in early 2018, will receive up to \$1 million.

Following four suborbital flights with a single vehicle in 2016, including three with science payloads on board, Blue Origin appears to be on the verge of beginning commercial operations for science flights in 2017. Virgin Galactic returned to flight test operations throughout 2017. Purdue University is partnered with a local second-grade class to fly a low-cost educational payload on a pending Blue Origin sub-orbital flight. The cost of the educational flight, \$8,000, is a fraction of that of K-12 sports and other activities, and thus, indicates that educational spaceflight is accessible to most schools in the country. The Next-gen Sub-orbital Researchers Conference in December 2017 is scheduled to showcase these and other

▼ **The new Zero Boil-Off Tank, or ZBOT,** cryogenic experiment was installed in the Microgravity Sciences Glovebox in the International Space Station in October 2017 with astronaut Joe Acaba's assistance.



NASA

advances in commercial sub-orbital spaceflight for research and education uses expected to blossom in 2018.

The NASA Flight Opportunities program in STMD Space Technology Mission Directorate continued its pursuit of spaceflight technology advances. In the past year, it awarded 12 technologies to fly in parabolic aircraft flights or commercial re-usable suborbital rockets. Technologies include regolith properties, microfluidics and manipulation of protein droplets. Earlier awards created technology payloads that are also expected to fly in 2018. ★



Missile Defense Agency

◀ **A David's Sling interceptor** completes a final test series before the Israeli Air Force declared it operational in January.

World news puts focus on missile defense

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.

International tensions brought missile systems to the forefront of current events in 2017. Particular attention was paid to missile defense technology as nations like North Korea and Iran demonstrated ballistic missiles of increasing sophistication.

Perhaps receiving the most notice was Lockheed Martin's **Terminal High Altitude Area Defense** system developed for the U.S. Missile Defense Agency. The U.S. sent a THAAD battery to South Korea in March to deter ballistic missiles from North Korea. In July, the system was tested against an Orbital ATK target released in midair north of Hawaii to simulate the terminal trajectory of an intermediate-range missile. A THAAD interceptor launched from the Pacific Spaceport Complex in Alaska detected, tracked and destroyed the target in a first-of-its-kind demonstration of the system's ability to directly hit such a threat.

While THAAD engages short- to intermediate-range threats, the **Ground-based Midcourse Defense** system is intended to destroy intercontinental ballistic missiles. In May, Boeing's GMD performed its first live-fire against an ICBM target. During the test, multiple sensors provided tracking data to the command and control system to develop a fire control solution. A GMD missile launched from Vandenberg Air Force Base, California, used a new terminal vehicle with improved thrusters for

better guidance when making course adjustments to intercept and destroy the target in space.

Missile defense also remained a priority in the Middle East, where Israel introduced two layers of its tiered air defense. In January, Israel accepted the **first Arrow 3 battery**, similar to GMD, that uses a two-stage interceptor to destroy ICBMs with a maneuvering kill vehicle at altitudes over 100 kilometers. This upper-tier defense system complements the midtier **David's Sling**, which became operational in April. Developed by Raytheon and Israel-based Rafael Advanced Defense Systems, David's Sling fires Stunner missiles against aircraft, long-range rockets, and tactical ballistic or cruise missiles.

In April, the U.S. Navy fired 59 Tomahawk land-attack cruise missiles against a Syrian military air base after a chemical weapons attack against civilians in the country. The Raytheon missile is in the process of being upgraded, including the addition of a multimode seeker to target moving ships. Meanwhile, at the end of 2016, the Navy started its **Next Generation Land Attack Weapon** program to develop a Tomahawk successor.

Similar replacement programs are underway to modernize the U.S. strategic missile inventory. In August, the Air Force awarded Ground-Based Strategic Deterrent contracts to Northrop Grumman and Boeing to develop proposals for an ICBM to replace the 1970s-era Minuteman III. Also needing to replace the Air-Launched Cruise Missile from the early 1980s, the Air force agreed to contracts with Lockheed and Raytheon to develop competing concepts for a nuclear cruise missile. Known as the Long-Range Standoff missile, the weapon would equip B-52, B-2 and B-21 bombers. Both the GBSD and LRSO are expected to be fielded in the late 2020s. ★



▲ A Dove cubesat shot this image of the Disneyland parking lot.

Record launch included 100 small satellites

BY MARTIN LINDSEY

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

Small satellites continue to transition from academic teaching tools to tools for commercial and government space missions. The number of small satellites on-orbit grew exponentially in 2017.

The Indian Space Research Organization set a record for a launch Feb. 15 with the Polar Satellite Launch Vehicle C37 mission, which deployed **104 satellites into sun-synchronous orbit**. More than 100 of these were small satellites, including 88 Planet Labs 3U-cubesat Flock-3p Doves and eight Spire Lemur-2 spacecraft. Planet Labs' Doves, combined with its satellites already in orbit, can "image all of the Earth's landmass every day," according to the company. Spire's satellites track ship traffic and gather global weather data through GPS radio occultation, which calculates

atmospheric properties from the deflection of GPS radio waves.

In another first for small satellites, Rocket Lab reached space with its inaugural "It's a Test" launch of the Electron rocket May 25 from its Mahia Peninsula launch site in New Zealand. The rocket did not make orbit due to misconfiguration of telemetry equipment owned and operated by a third-party contractor. The event still marked the first orbit-capable launch from New Zealand.

NASA's **Cyclone Global Navigation Satellite System** of eight microsattellites — launched in December 2016 — started delivering worldwide tropical cyclone forecasting data in early 2017. Developed by Southwest Research Institute and the University of Michigan, CYGNSS increases the frequency of ocean surface wind measurements so storm forecasters can improve predictions of how the intensity of a tropical storm will change over time.

In another groundbreaking small satellite science mission, the John Hopkins University Applied Physics Laboratory in partnership with NASA, Draper Laboratory and L-1 Standards and Technology conducted the **Radiometer Assessment using Vertically Aligned Nanotubes mission**, completed in August. RAVAN began collecting data from Earth's orbit Jan. 25. With a radiometer the size of a deck of cards, the RAVAN 3U-cubesat measures the Earth's outgoing radiation across the entire spectrum from ultraviolet to far-infrared. The program's 2012 proposal to NASA explains that the relatively small size and cost of cubesats like RAVAN make it more efficient for such constellations to "measure Earth's radiative diurnal cycle and absolute energy imbalance to climate accuracies" — globally 0.3 watts per square meter.

This past year also saw virtual explosive growth in the development of **propulsion systems and de-orbiting technologies** for small satellites. The proliferation of small satellites into low Earth orbit and beyond has many governments, industry organizations and the small-satellite community grappling with the increasing risk of orbital collisions. As highlighted in the July-August issue of Aerospace America, companies are developing, building and flying a variety of electromagnetic and chemical propulsion systems tailor-made generally for microsattellites and specifically for cubesats. Similarly, a wide variety of de-orbiting technologies are being explored to enable small satellites to fly at increasingly higher LEO and still comply with the United Nations guideline to de-orbit within 25 years of end-of-mission. ★

Next steps in sustaining human presence in space

BY BARBARA IMHOF, MARIA JOÃO DURÃO AND THEODORE HALL

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

► **Inside the EDEN ISS** semiclosed aeroponic greenhouse, researchers are growing tomatoes, Swiss chard, strawberries, cucumbers, lettuce and chives.



Space agency heads are gearing up toward human exploration beyond Earth orbit. With U.S. funding to operate the International Space Station planned only through fiscal 2024, further goals beckon. The China National Space Agency plans to establish a lunar base within 20 years. Russia and Europe also show high interest in the moon, and NASA may join. Private companies such as Blue Origin and SpaceX have also announced plans for lunar logistics support. Although the definite aims are not yet settled, developments for a sustained human presence on an extraterrestrial body must be prepared years in advance.

NASA awarded the team of Foster + Partners and Branch Technology with first place for completing Phase 2 of the **3D-Printed Habitat Challenge** in August. Pennsylvania State University was second. This competition aims to advance construction technology for settling on planetary bodies using in-situ materials. The teams had to demonstrate that with their own printers they could use additive manufacturing processes to print beams, cylinders and other geometric shapes relevant to housing that were then tested for their structural capabilities. José Pinto Duarte of Penn State reported on the last day of the competition:

“Our dome ... passed the second strength test, which allowed us to score points and kept us in the race for the first place. In the final strength test, our concrete dome withstood 792 kilograms after just 18 hours of curing! The other team was using thermoplastics, which cured completely 12

hours after being printed. ... Their dome was able to withstand a slightly larger load than ours.”

Simulation missions are also continuing in facilities worldwide. In May, the **China National Space Agency opened its “lunar palace,” Yuegong-1 again.** Two groups of four volunteers will spend 60 days and then 200 days confined in the facility, which houses an intricate life support system, habitation spaces and two greenhouses. In September, HI-SEAS, the **Hawaii Space Exploration Analog and Simulation**, concluded its fifth experiment to study how isolation and the lack of privacy in a small group may affect the social aspects of future space expeditions. The experiment, which began in January, involved six people. The facility is built high on the flank of the Mauna Loa volcano because the volcanic surface resembles Martian soil.

A sustainable human-tended base will require a place to grow food for the crew. The **Ground Demonstration of Plant Cultivation Technologies for Safe Food Production in Space**, named EDEN ISS, completed its greenhouse in May and put it through initial tests from June through September before shipping it to Antarctica for a year of trial at the German Neumayer III Station. EDEN ISS incorporates a semiclosed aeroponic greenhouse for growing tomatoes, Swiss chard, strawberries, cucumbers, lettuce, chives and other vegetables. The double-cargo-container-size structure includes an international standard payload rack-size greenhouse experiment in preparation of testing on the International Space Station. Engineers and scientists from 14 countries and the space architecture company LIQUIFER Systems Group have been developing this European Union-funded project.

Private companies are also stepping up with space exploration. Maryland-based Genesis Engineering Solutions’ **Single-Person Spacecraft** underwent tests in 2017, including neutral buoyancy tests assessing ingress/egress, internal layout, restraints and controllers; an impact test of the polycarbonate dome; and flight simulator assessment of propellant usage. Over 75 percent of the pressurized crew enclosure drawings for SPS were completed this year, and the pressure dome engineering development unit was manufactured. The company also signed a memorandum of understanding with Sierra Nevada Corp. in May for, among other things, contributing to Sierra Nevada’s contract for NASA’s Deep Space Gateway. SPS will provide a full-pressure shirtsleeve environment for its sole occupant to control robotic arms for servicing NASA’s gateway and Mars transit habitats as well as for exploring low-gravity asteroids or moons. ★

Astronauts on ISS control robots remotely

BY JIAN-FENG SHI, KATHERINE STAMBAUGH AND GARDELL GEFKE

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

Space robotics has had an exciting year — ranging from International Space Station remote robot control technology demonstrations and on-orbit servicing mission milestones to commercial lunar missions and Earth demonstrations of future Mars mission technologies.

In June, the Japanese Aerospace Exploration Agency delivered Int-Ball to the ISS. Int-Ball is an autonomous camera drone that's controlled from JAXA's Tsukuba Space Center in Japan. By contrast, in August, Italian astronaut Paolo Nespoli controlled a robot called Rollin' Justin — in Oberpfaffenhofen near Munich — from the ISS in a European Space Agency experiment to demonstrate robot control in a future Mars mission. The German robot completed complex tasks in a semi-autonomous capacity.

In February, NASA's Goddard Space Flight Center Satellite Servicing Projects Division's Raven module launched to the ISS. The Raven demonstration tracks incoming payloads to the ISS with machine vision, closed-loop rendezvous. The Satellite Servicing Projects Division completed development efforts and fabrication for Robotic Refueling Mission 3 and is working toward completing system integration and testing. Robotic Refueling Mission 3 will demonstrate the never-before-attempted transfer of cryogenics and xenon on-orbit in early 2018. Robotic Refueling Mission 1 received the AIAA Space Automation and Robotics Technical Excellence Award in September.

The Satellite Servicing Projects Division reviewed in June and July NASA preliminary designs for the Restore-L mission payload and bus. Restore-L will be the first time robotically refuel a satellite not designed to be serviced on-orbit.

For on-orbit servicing, Space Systems Loral, based in Palo Alto, California, secured a contract in February with DARPA for the Robotics Servicing of Geosynchronous Satellites program. The program aims to perform high-resolution inspections; correction of mechanical anomalies such as solar array and antenna deployment malfunctions; assistance with relocation and other orbital maneuvers; installation of attachable payloads, enabling upgrades or entirely new capabilities for

existing assets; and satellite refueling. In addition, in September, Space System Loral completed a major ground demonstration of an ultra-light robotic system and advanced command and control software for NASA's Dragonfly program for on-orbit satellite assembly.

After 10 years of competition under the Google Lunar XPRIZE, five finalist teams — the United States' Moon Express, Japan's Hakuto, India's Team Indus, Israel's SpaceIL and an international team Synergy Moon — have secured launches by the end of this year for sending each team's spacecraft to the moon. The XPRIZE Foundation will award a total of \$30 million. The first \$20 million will be awarded to the first privately funded team to land a spacecraft on the moon, travel 500 meters and transmit HD video and images of its mission back to Earth. Two other \$5 million prizes will go to the second-place winner and as a bonus for completing extra tasks like surviving the lunar night.

NASA's Jet Propulsion Laboratory in Pasadena, California, has developed several key technologies for the Mars Curiosity rover. The six aluminum wheels on the rover are starting to show significant signs of wear after traveling more than four years and 17 kilometers on Mars. In March, JPL uploaded to the rover a new algorithm to use real-time data to adjust each wheel's speed, reducing pressure from rocks. In February, JPL used artificial intelligence and the Opportunity rover to capture dust devils swirling across the Martian surface.

NASA's Centennial Challenges program held the Space Robotics Challenge in June. Twenty of 400 teams were selected for the final competition. Four teams won a total of \$300,000 for completing a series of simulation tasks in a virtual environment while controlling the Robonaut 5 Valkyrie robot from Johnson Space Center in Houston. The tasks simulated rectifying failures of future Mars missions, including aligning a communications dish, repairing a solar array and fixing a habitat leak. ★

▼ **The Japanese Aerospace Exploration Agency's Int-Ball camera drone** moves through the International Space Station under the control of flight controllers and researchers at Tsukuba Space Center in Japan.



JAXA/NASA



SpaceX

◀ A previously launched SpaceX Falcon 9 booster

lands after the SES-10 satellite launch.

Blue Origin revealed its design for the Blue Moon lander in April at the 33rd Space Symposium in Colorado Springs, Colorado. The Blue Moon lander would leverage the capability of vertical takeoff; the plan is for it to deliver cargo to the lunar surface in the 2020s. The lander will be optimized for launch by NASA's Space Launch System but could also be launched by other rockets, such as United Launch Alliance's Atlas 5 or Blue Origin's New Glenn. This lander could help open the doors to settlements on the moon.

In addition to commercial space logistics activities, in March, NASA revealed a plan for a phased exploration approach with the next steps being a Deep Space Gateway and Deep Space Transport. According to the plan, during the first phase of the exploration, a crew-tended spaceport would be built in cislunar space with an electric propulsion system, repurposed from the canceled Asteroid Redirect Mission, for its mobility. The gateway would support activities in cislunar space and could serve as a staging point for access to the lunar surface or farther destinations. Space Launch System rockets and Orion spacecraft would deliver and assemble the Deep Space Gateway. During the second phase of exploration, the Deep Space Transport would be developed as a reusable transportation capability for crewed missions to farther destinations, such as Mars. The fruition of these plans would be a significant step toward expanding humanity's presence beyond low Earth orbit. Space logistics planning and implementation will be a key consideration for the Deep Space Gateway and Deep Space Transport development and operations.

On the academia side, in August the Space Systems Optimization Laboratory at the University of Illinois at Urbana-Champaign completed a one-year study funded by United Launch Alliance to analyze the transportation architecture for cislunar resource economy. The study analyzed the technical and economic impact of lunar resources and other infrastructure systems in two case studies: regular delivery of payload from LEO to geosynchronous Earth orbit using lunar resources, and regular delivery of crew to the moon and back. This study could be an important stepping stone toward space commercialization using cislunar infrastructure. ★

Koki Ho works at the University of Illinois at Urbana-Champaign.

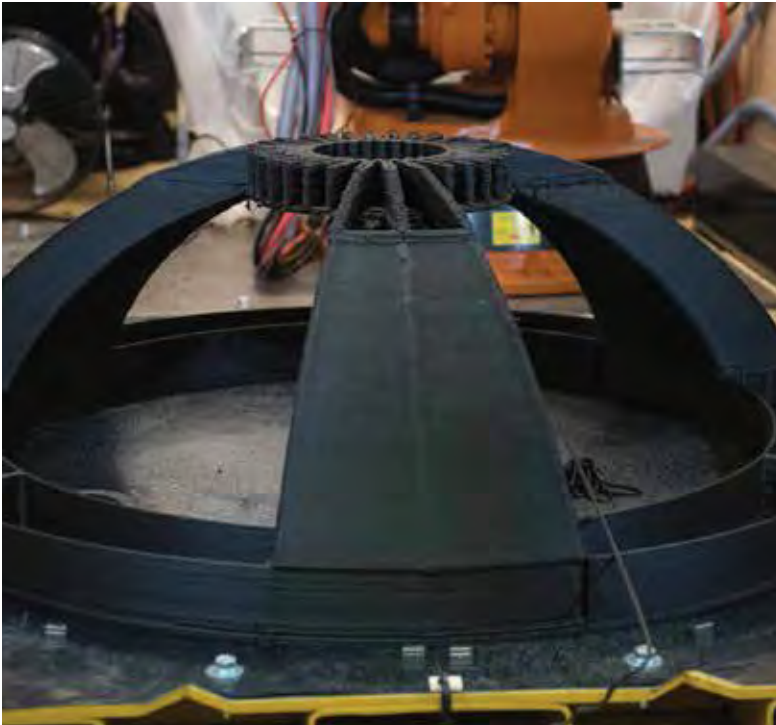
Contributors: Lauren Paunescu, Robert Shishko and Kandyce Goodliff

Potential for more affordable exploration

BY KOKI HO

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

Commercial space logistics marked significant milestones in 2017. One of the largest events was SpaceX's reuse of the first stage of the Falcon 9 rocket in March. The reused Falcon 9 booster B1021 was first used to deliver a Dragon spacecraft on the CRS-8 mission April 8, 2016; after its recovery on a drone ship, it was refurbished and reused for the SES-10 mission March 30, 2017. After delivery of the SES-10 mission, B1021 was recovered a second time. This achievement could revolutionize next-generation space logistics by enabling launches at a substantially lower cost.



NASA

In-situ projects span from habitats to Andy Weir's "Oxygenator"

BY MICHAEL HECHT, FORREST MEYEN AND JUSTIN CYRUS

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.

▲ **A 3-D-printed dome structure** that is part of NASA's 3D-Printed Habitat Challenge is displayed at Bradley University in Illinois.

Space instruments and missions demonstrating in-situ resource utilization, or ISRU, are preparing for launch in the next few years, and industry-NASA partnerships to develop off-world resource utilization technologies are flourishing. The challenge of overcoming the gravity well — for both landing and launch — continues to drive the field, with emphasis on processing both carbon dioxide and water resources for propellant production.

At NASA, the **Mars Oxygen ISRU Experiment**, or MOXIE, passed critical design review in May and is on track to test carbon dioxide-to-oxygen conversion on Mars as a payload on the Mars 2020 Lander. A collaboration among the NASA Science, Human Exploration and Operations, and Space Technology mission directorates led by the Massachusetts Institute of Technology and built by NASA's Jet Propulsion Laboratory, MOXIE is a scale model of the "Oxygenator" described by Andy Weir in "The Martian."

A mission definition review for Human

Exploration and Operations Mission Directorate's Resource Prospector is scheduled for 2018; the drill (built by Honeybee Robotics), spectrometer (built by NASA's Ames Research Center) and volatile analysis system (built by NASA's Johnson and Kennedy space centers) passed integrated thermal vacuum tests and demonstrated low-level water detection capabilities in 2017. The directorate also announced a new ISRU Technology program focused on component, subsystem and system maturation in the areas of water and volatiles resource acquisition and processing. The Space Technology Mission Directorate's NASA Innovative Advanced Concepts program announced support of advanced efforts ranging from asteroid mining to space tethers.

Universities continue to advance ISRU technology and education. In August, Bradley University ran the **NASA 3D-Printed Habitat Centennial Challenge Phase 2** competition in Edwards, Illinois, and Colorado School of Mines announced its 2018 debut of the first graduate program devoted to exploration, extraction and use of resources in space. Missouri University of Science and Technology, the Colorado School of Mines and the University of Hawaii worked on developing **technology to extract water from carbonaceous asteroids**. Michigan Technological University teamed with JPL to demonstrate water extraction on Mars from gypsum and partnered with Honeybee Robotics to develop rock-welding technology for landing pad construction.

Startups in the nascent field of deep space mining are progressing from studies to flight demonstrations. Seattle-based Planetary Resources, buoyed by a 25 million-euro investment from the government of Luxembourg, completed launch readiness for **Arkyd 6**, its second technology demonstration spacecraft. California's TransAstra Corp. announced in April receipt of a NASA Tipping Points award to demonstrate asteroid tracking technology in space and a separate award to develop an optical mining testbed on Earth.

Luxembourg's Chamber of Deputies followed up its investment in Planetary Resources by passing a law in July recognizing **the right to space-based resources**. And Team Hakuto, Japan's ISRU-themed competitor for the Google XPRIZE, signed a rideshare agreement in December 2016 with India's Team Indus to send a rover to a permanently shadowed region of the lunar surface in search of water ice by the end of 2017. ★

Contributor: Julie Kleinhenz works at the Massachusetts Institute of Technology.



U.S. Air Force

◀ **The U.S. Air Force X-37B Orbital Test Vehicle 4** landed at NASA's Kennedy Space Center in May after being in orbit for 718 days.

Commercial and government space push forward

BY JOHN BLOOMER

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

This year saw both commercial industry and U.S. government programs make important achievements toward unprecedented space-based capabilities in domains such as communications, earth imaging, astronomy and national defense.

On the commercial front, SpaceX made a pioneering advance in March with the **first reuse of an orbital-class rocket**. The Falcon 9 first-stage rocket delivered the SES-10 communications satellite into geostationary orbit. SpaceX had originally flown and landed the rocket on a barge in April 2016. Launch vehicle reuse is regarded as a key element of lower cost access to space, and SpaceX projects an ultimately realizable 30 percent cost reduction for its customers. In June, SpaceX flew a refurbished Dragon capsule to the International Space Station — another first. The capsule had flown on a 2014 ISS mission and had some parts — notably the heat shield — replaced prior to the second flight.

SpaceX also conducted the first two of eight missions to populate the **next-generation Iridium NEXT communications satellite constellation**. January and June launches each put 10 satellites into low Earth orbit. When the 75-satellite constellation is complete, Iridium NEXT will provide global communications and global air traffic surveillance. Virginia-based Aireon has partnered with Iridium to equip each satellite with receivers

to collect location and airspeed data broadcast by commercial aircraft. For SpaceX, the January launch was an important return-to-flight mission following the 2016 explosion of a Falcon 9 on the launch pad.

In April, **Planet closed a deal to purchase Google's Terra Bella satellite business**. The acquisition immediately added seven high-resolution Earth imaging satellites to Planet's constellation of 100 moderate-resolution cubesats. Building variety into what data can be collected daily for any location on Earth enlarges Planet's addressable market. As part of the deal, Google became a shareholder in Planet as well as a client, agreeing to purchase data that will support its mapping and analytics products.

NASA's Juno spacecraft marked its first year in orbit around Jupiter on July 4 and continues to execute its science mission, which is scheduled to last until at least July 2018. Juno's suite of nine instruments is designed to improve understanding of Jupiter's structure and origin. Because of its highly elliptical orbit, Juno can collect data at distances ranging from 5 million kilometers to as close as 2,100 km. This year's highlight was the July 10 low-altitude pass over the famous Great Red Spot, a storm structure more than 20,000 km across that has persisted since at least 1830.

The **James Webb Space Telescope** team completed acoustic and vibration testing of the integrated optical telescope and science instrument assembly in March at NASA's Goddard Space Flight Center. In May, the hardware was delivered to NASA's Johnson Space Flight Center for cryogenic vacuum testing, which started in July. The telescope is scheduled to launch in 2018.

The U.S. Air Force concluded the fourth flight of its **X-37B unmanned space plane** in May with its first landing at NASA's Kennedy Space Center. The small shuttle-like vehicle spent 718 days in orbit, breaking the previous X-37B mission record by more than 40 days. The Air Force advertises the X-37B as a space technology demonstration platform, although mission details remain secret.

In March, the Air Force announced acquisition of the first on-orbit data from its newest space-based infrared system geosynchronous orbit satellite. It's the third operational GEO platform in the SBIRS, which is the main U.S. system for detecting launches and predicting trajectories for intercontinental and theater ballistic missiles. ★

► **The Phobos L1 Operational Tether Experiment spacecraft**, seen in an artist's rendering, is supposed to hover for long periods at the Mars-Phobos Lagrangian 1 point and suspend a tethered sensor platform above the moon's surface.



Space tether test focused on satellite pair

BY SVEN G. BILÉN

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

A number of novel mission concepts enabled by space tethers were proposed in 2017. A research team from the Massachusetts Institute of Technology and Airbus DS Space Systems — in cooperation with the University of Padova in Italy — in February completed tether experiments in microgravity using the **Synchronized Position Hold, Engage, Reorient, Experimental Satellites, or SPHERES**, on the International Space Station. The testing focused on understanding the dynamics of a satellite pair connected by a nonconductive tether.

Under a NASA Innovative Advanced Concepts Phase 1 award, NASA's Langley Research Center in Virginia and its partner Star Technology and Research in June began a study of the **Phobos L1 Operational Tether Experiment**. The PHLOTE spacecraft will perform long-term hover mode operations at the Mars-Phobos Lagrangian 1 point and suspend a tethered sensor platform that can “float” just above the moon's surface. If desired, the tethered sensors can be placed directly on the surface for detailed measurements of the regolith. L1s are unstable orbital locations; active control is needed to stay there. The PHLOTE mission will incorporate the Navigation Doppler Lidar sensor for precise relative position and rate knowledge along with high-efficiency electro-spray thrusters for propulsion. Adjusting

the tether length supports station keeping and minimizes propellant consumption.

Researchers at NASA's Goddard Space Flight Center outlined in August the **Bi-sat Observations of the Lunar Atmosphere above Swirls** mission concept. A “sky crane” of two cubesats would lower one of the satellites toward the lunar surface on a 180-kilometer tether so it could orbit about 10 km above the lunar surface to investigate swirling patterns in more than 100 locations.

With support from the Canadian Space Agency, researchers at York University developed a mission concept this year called **Deorbiting Spacecraft using Electrodynamic Tethers** to demonstrate the deorbit of space debris by electrodynamic tethers. Two 1U cubesats connected by a 100-meter tape-type tether will be launched from the ISS in 2019.

In May, researchers at Penn State described a concept for “**embodied energy repurposing**” via energy-harvesting electrodynamic tethers. The concept proposes transferring the orbital energy of unused spacecraft or debris to the electrical subsystem of another spacecraft. The transfer of energy would simultaneously power the useful spacecraft while deorbiting the other.

Under two NASA Innovative Advanced Concepts awards, researchers at NASA's Marshall Spaceflight Center performed a series of **plasma chamber tests of electric sail propulsion systems**. Electric sail propulsion is enabled by the deployment of multiple 20-km-length, 0.2-millimeter-diameter tethers. Work has focused on experimental plasma chamber testing to provide data against which to benchmark; an electric sail spacecraft particle-in-cell theoretical model being developed by the University of Alabama in Huntsville; mission design work; development, investigations and experimentation of simulated space tether deployment; and conceptual design of an Electric Sail Technology Demonstrator Mission spacecraft. The electric sail mission is comprised of two identical 6U cubesats deployed together from a spacecraft in cislunar space. Each spacecraft has 8,250 meters of conductive tether that will be deployed via a cold gas propulsion system and, once deployed to the 16,500-meter length, those thrusters will add a radial component of thrust in an equal and opposite direction to enable the system to rotate about the tether midpoint at five to 10 revolutions per day.

In October, the Miniature Tether Electro-dynamics Experiment led by the University of Michigan was finishing development of a custom high-voltage electron collection and emission system and a Langmuir Probe for plasma characterization. It is scheduled to launch in 2018 as part of NASA's CubeSat Launch Initiative. ★

Commercial launch companies and NASA chart successes

BY DALE ARNEY

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

Commercial companies provided frequent, reliable access to space in 2017 while preparing for the future of space exploration. SpaceX returned to flight with a Falcon 9 launch Jan. 14. By June, the company had surpassed its previous high mark of eight launches in a year, including flights of previously flown boosters, a refurbished Dragon capsule and three launches within a 12-day span. SpaceX's heavy lift vehicle, Falcon Heavy, underwent hot-fire testing at its test facility in Texas in preparation for its planned Dec. 29 launch.

United Launch Alliance delivered commercial and government payloads on its Atlas and Delta rockets throughout the year. ULA's 120th launch was in August.

In July, Blue Origin founder Jeff Bezos shared photos of the company's **New Glenn orbital rocket assembly factory** under construction at Cape Canaveral Air Force Station in Florida. New Glenn is scheduled to be operational by 2020. The BE-4, Blue Origin's methane/oxygen engine being developed for New Glenn, is also under consideration for use on ULA's Vulcan rocket. In 2017, BE-4 hardware began integrated testing in Texas in preparation for engine production in 2019.

► **Liquid oxygen and liquid hydrogen tanks** for NASA's Space Launch System are being built and processed at the Vertical Assembly Building at NASA's Michoud Assembly Facility in New Orleans.



NASA

Many components of NASA's Space Launch System, designed to send astronauts to the lunar vicinity in the 2020s, were assembled in preparation for an uncrewed test flight in 2019. The interim cryogenic propulsion stage — the second stage of the SLS and first integrated piece of SLS hardware — was delivered in July to the Space Station Processing Facility at Kennedy Space Center, where it will remain until stacking operations for Exploration Mission 1.

For NASA's Commercial Crew Program to deliver crew to the International Space Station starting in 2019, SpaceX and Boeing continued **ground testing of the Dragon and Starliner spacecraft**, respectively, in preparation for crewed test flights in 2018.

SpaceX and Orbital ATK delivered logistics to the ISS several times as part of the Commercial Resupply Services contract. After the return to flight of the upgraded Antares rocket in 2016, Orbital ATK used ULA's Atlas 5 for its first delivery in 2017. Sierra Nevada's Dream Chaser, a lifting-body vehicle that will resupply the ISS starting in 2020 atop ULA's Atlas 5, completed a captive carry test in August at NASA's Armstrong Flight Research Center.

Launch vehicles from international space agencies had significant achievements in 2017. Soyuz delivered crew to the ISS in April, July and September, with a planned launch in December. The July Soyuz MS-05 mission was the 134th flight of a Soyuz spacecraft. The Ariane 6, the European Space Agency launch vehicle scheduled to begin flight in 2020, passed a major milestone in April permitting the production of ground qualification models. China's **Long March 5 rocket suffered a failure** in July, with planned return to flight by 2018 with a mission to robotically return samples from the moon. In June, India launched the Geosynchronous Satellite Launch Vehicle Mark 3 — its most powerful launch vehicle to date. India also launched a record-setting 104 small or cube satellites to orbit on a single launch in February using its Polar Satellite Launch Vehicle.

Small launch vehicles continued their progress toward meeting the demand of the growing small satellite market. In May, California-based Rocket Lab performed a partially successful test flight of the first Electron rocket, and Arizona-based Vector Space Systems performed the first suborbital test flight of its Vector-R rocket. Virgin Orbit performed hot-fire testing of the NewtonFour engine, which will power its LauncherOne vehicle's second stage during its first flight, planned for late 2018.

Virgin Galactic completed an **unpowered glide test of its VSS Unity spaceplane** in August and plans to send tourists to space starting in 2018. ★



U.S. Missile Defense Agency

◀ **A U.S. Navy SM-6 missile** fired from the USS John Paul Jones intercepted this medium-range ballistic missile target launched from the Pacific Missile Range Facility on Kauai, Hawaii.

Missile defense tests show progress

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.

President Ronald Reagan presented missile defense as a means to make nuclear weapons “impotent and obsolete.” 2017 saw a need for that with concerns regarding North Korea. The year also saw progress on the path to missile defense.

For the first time, the **Ground-based Mid-course Defense** segment of the U.S. national missile defense system intercepted an intercontinental ballistic missile. In the May 30 test — designated Flight Test Ground-Based Interceptor 15 — the ICBM was launched from the Kwajalein Atoll in the Pacific Ocean. Multiple sensor systems, including a Sea-Based X-band radar positioned near Hawaii, tracked the target and provided information to ground-based controllers. After an intercept course was developed, a GMD ground-based interceptor was launched from Vandenberg Air Force Base, California. Its exo-atmospheric kill vehicle intercepted and destroyed the target in a direct collision. The goal was to have 44 ground-based interceptors deployed by the end of 2017 — 40 at Fort Greely, Alaska, and four at Vandenberg. The 44th interceptor was installed at Fort Greely on Nov. 2.

The **Terminal High Altitude Area Defense**, or THAAD, system performed two intercepts of

ballistic missiles during tests in July. In both cases, the battery was based at the Pacific Spaceport Complex in Alaska. Both tests employed targets that U.S. Air Force C-17 Globemaster 3 aircraft airdropped over the Pacific Ocean. The intercept missiles were launched from a portable, wheeled ground vehicle that holds eight missiles and can perform multiple launches for multiple intercepts. Soldiers in Alaska controlled the THAAD using the same procedures that would be used in combat. They were not informed of the target launch times.

The first test was July 11. In the test — designated Flight Test THAAD 18 — the THAAD system intercepted an intermediate-range ballistic missile. The second test, conducted July 30, was designated Flight Experiment THAAD 01. Its primary goal was to gather threat data from a THAAD interceptor in flight. In this test, the THAAD system intercepted a medium-range ballistic missile. These tests were the 14th and 15th intercepts for THAAD (in 14 and 15 tests, respectively) since the engineering and manufacturing development phase of the program began in 2000.

A U.S. Navy **SM-6 missile** intercepted a medium-range ballistic missile during a test Aug. 29. The test began with the launch of the target missile from Kauai, Hawaii. The guided-missile destroyer USS John Paul Jones detected the missile and shot it down with the Standard Missile variant. The SM-3 Block 2A variant was tested Feb. 3 and June 21. The February test led to an intercept, but the June test did not. This missile capability is being developed jointly with Japan. ★

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-  **Meet & Greet with 2017 Best Paper Authors**
Engage with the best paper authors from the 2017 AIAA SciTech Forum and hear what they are working on now.
-  **What You Need to Know About Cybersecurity**
Learn the facts about aerospace cybersecurity and how you can participate in the Cybersecurity Symposium.
-  **Design Challenges**
Show off your engineering prowess and teamwork by participating in fun and rewarding design challenges!

Find a full schedule of activities at
scitech.aiaa.org/theHUBschedule

The Exposition Hall and the HUB will be open 9-11 January 2018.



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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

Notes About the Calendar

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
2017			
4–8 Dec†	Flight Software Workshop	Laurel, MD (www.flightsoftware.org)	28 Aug 17
7 Dec	DirectTech Webinar—Materials for Hypersonic Vehicles	Virtual (aiaa.org/onlinelearning)	
14 Dec	DirectTech Webinar—Structures for Hypersonic Vehicles	Virtual (aiaa.org/onlinelearning)	
2018			
6–7 Jan	5th International Workshop on High-Order CFD Methods	Kissimmee, FL	
6–7 Jan	Future CFD Technologies Workshop: Bridging Mathematics and Computer Science for Advanced Aerospace Simulation Tools	Kissimmee, FL	
6–7 Jan	Aircraft and Rotorcraft System Identification Engineering Methods for Manned and UAV Applications with Hands-On Training Using CIFER® Course	Kissimmee, FL	
6–7 Jan	Large Eddy Simulation of Turbulent Combustion: Theory, Modeling and Practice Course	Kissimmee, FL	
6–7 Jan	Introduction to Software Engineering Course	Kissimmee, FL	
6–7 Jan	Stochastic Mechanics of Materials and Structures Course	Kissimmee, FL	
6–7 Jan	Missile Guidance Course	Kissimmee, FL	
7 Jan	Aeroelastic Wind Tunnel Testing and Aeroelasticity Considerations for Non-Aeroelastic Tests Course	Kissimmee, FL	
7 Jan	Space Standards and Architectures Workshop	Kissimmee, FL	
8 Jan	2018 Associate Fellows Recognition Ceremony and Dinner	Kissimmee, FL	
8–12 Jan	AIAA SciTech Forum (AIAA Science and Technology Forum and Exposition) Featuring: – AIAA/AHS Adaptive Structures Conference – AIAA Aerospace Sciences Meeting – AIAA Atmospheric Flight Mechanics Conference – AIAA Information Systems — Infotech@Aerospace Conference – AIAA Guidance, Navigation, and Control Conference – AIAA Modeling and Simulation Technologies Conference – AIAA Non-Deterministic Approaches Conference – AAS/AIAA Space Flight Mechanics Meeting – AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference – AIAA Spacecraft Structures Conference – Wind Energy Symposium	Kissimmee, FL	12 Jun 17
22–25 Jan †	64th Annual Reliability & Maintainability Symposium (RAMS)	Reno, NV (Contact: http://www.rams.org)	
1 Feb	DirectTech Webinar—Introduction to Computational Aerodynamics	Virtual (aiaa.org/onlinelearning)	
22 Feb	DirectTech Webinar—UAV Conceptual Design & Testing Using Computer Simulations	Virtual (aiaa.org/onlinelearning)	
21 Mar	AIAA Congressional Visits Day (CVD)	Washington, DC (aiaa.org/CVD)	
1 May	2018 Fellows Dinner	Crystal City, VA	
2 May	Aerospace Spotlight Awards Gala	Washington, DC	

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

- AIAA Continuing Education offerings
- AIAA Symposiums and Workshops

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
3–10 Mar †	IEEE Aerospace Conference	Big Sky, MT (Contact: www.aeroconf.org)	
8–10 May	AIAA DEFENSE Forum (AIAA Defense and Security Forum) Featuring: – AIAA Missile Sciences Conference – AIAA National Forum on Weapon System Effectivenss – AIAA Strategic and Tactical Missile Systems Conference	Laurel, MD	30 Nov 17
28–30 May †	25th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (Contact: www.elektropribor.spb.ru)	
28 May–1 Jun	SpaceOps 2018: 15th International Conference on Space Operations	Marseille, France (Contact: www.spaceops2018.org)	6 Jul 17
25–29 Jun	AIAA AVIATION Forum (AIAA Aviation and Aeronautics Forum and Exposition) Featuring: – AIAA/CEAS Aeroacoustics Conference – AIAA Aerodynamic Measurement Technology and Ground Testing Conference – AIAA Applied Aerodynamics Conference – AIAA Atmospheric Flight Mechanics Conference – AIAA Atmospheric and Space Environments Conference – AIAA Aviation Technology, Integration, and Operations Conference – AIAA Flight Testing Conference – AIAA Flow Control Conference – AIAA Fluid Dynamics Conference – AIAA/ASME Joint Thermophysics and Heat Transfer Conference – AIAA Modeling and Simulation Technologies Conference – AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference – AIAA Plasmadynamics and Lasers Conference	Atlanta, GA	9 Nov 17
25–29 Jun†	15th Spacecraft Charging Technology Conference (SCTC)	Kobe, Japan (Contact: http://www.org.kobe-u.ac.jp/15sctc/index.html)	
3–6 Jul†	ICNPAA-2018 - Mathematical Problems in Engineering, Aerospace and Sciences	Yerevan, Armenia (Contact: http://www.icnpaa.com)	
9–11 Jul	AIAA Propulsion and Energy Forum (AIAA Propulsion and Energy Forum and Exposition) Featuring: – AIAA/SAE/ASEE Joint Propulsion Conference – International Energy Conversion Engineering Conference	Cincinnati, OH	4 Jan 18
19–23 Aug†	2018 AAS/AIAA Astrodynamics Specialist Conference	Snowbird, UT (http://www.space-flight.org)	
17–19 Sep	AIAA SPACE Forum (AIAA Space and Astronautics Forum and Exposition) Featuring: – AIAA Complex Aerospace Systems Exchange	Orlando, FL	8 Feb 18
1–5 Oct†	69th International Astronautical Congress	Bremen, Germany	

Candidates Announced for 2018 Council of Directors Election

AIAA's Council Nominating Committee has selected candidates for next year's openings on the Council of Directors. The Committee's Chair, Jane Hansen, and AIAA Governance Secretary, Christopher Horton, confirmed the names of the director candidates who will appear on the 2018 ballot:

Director—Aerospace Sciences Group

Brett Ridgley, Raytheon Missile Systems Company
Robin Vermeland, Lockheed Martin Aeronautics Company

Director—Aerospace Design & Structures Group

Carlos Cesnik, University of Michigan
Thiagarajan Krishnamurthy, NASA Langley Research Center

Director—Region III

Daniel Jensen, Rolls-Royce Corporation

Director—Region VI

Darin Haudrich, Northrop Grumman Corporation
Jeffery Puschell, Raytheon Space and Airborne Systems

The election will open in February 2018.

CALL FOR NOMINATIONS

AIAA Foundation Award for Excellence

The AIAA Foundation Award for Excellence is the highest award presented by the AIAA Foundation Board of Trustees, recognizing excellence within the aerospace community. Eligible nominees will offer a unique achievement or extraordinary lifetime contributions inspiring the global aerospace community.

Nomination Deadline: 15 January 2018

For more information or to make a nomination, please visit aiaa.org/FoundationAwardForExcellence.

AIAA Associate Fellows Recognition Ceremony and Dinner



Celebrate the Class of 2018 AIAA Associate Fellows

Monday, 8 January 2018

Join us as we recognize exemplary professionals for their accomplishments in engineering or scientific work, outstanding merit, and contributions to the art, science, or technology of aeronautics or astronautics.

The Class of 2018 AIAA Associate Fellows will be officially recognized during the Associate Fellows Recognition Ceremony and Dinner, to be held in conjunction with the 2018 AIAA SciTech Forum at the Gaylord Palms in Kissimmee, Florida, on Monday evening, 8 January 2018.

Please support your colleagues, and join us for the induction of the Class of 2018 AIAA Associate Fellows. Tickets to this celebrated event are available on a first-come, first-served basis and can be purchased for \$100 via the 2018 AIAA SciTech Forum registration form, 2018 Associate Fellows Dinner event registration form, or onsite (based on availability).

For more information and to register online, please visit
www.aiaa.org/AssociateFellowsDinner2018





AIAA was inducted into the International Air & Space Hall of Fame at a gala celebration at the San Diego Air & Space Museum's Pavilion of Flight. More than 25 student and professional AIAA members and staff joined 350 other guests at the 9 November event. The left photo shows Executive Director Sandra Magnus and Chief Operating Officer Angelo Iasiello accepting an original painting, certificate, and medal on behalf of the Institute from George Gould (far left) and Ramin Pourteymour (far right), members of the Board of Directors, San Diego Air & Space Museum. The above photo shows members of the AIAA San Diego Section, AIAA San Diego State University Student Branch, volunteer leaders, staff, and other Institute guests.

Sustainability in Engineering

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

The Society and Aerospace Technology Integration and Outreach Committee (SAT IOC) has a key objective to engage in topics linking society and technology. Even though aerospace technology specifies a key focal point of this committee, occasionally, it is equally beneficial to glance at the impact of technology across a wide range of different engineering disciplines for a given topic. This train of thought can also be expanded to multidisciplinary subjects. Sustainability is an exemplary topic in this regard. Whether related to reusable launch vehicles or energy-efficient airport buildings, the role of sustainability is of paramount importance. Dependent on the discipline of interest, interpretations about sustainability take an abundant number of thought-provoking paths in engineering.

On 9 November, the 2017 Orange County Engineering Council (OCEC) Leaders Forum, with the theme "Sustainability in Engineering," was hosted by the OCEC in Orange County, CA. This event enabled discussions about sustainability across a broad range of engineering disciplines through a panel session with key experts in their respective fields. The event addressed cross-disciplinary sustainability opportunities in Aerospace, Transportation, Civil, Architectural, Computer, and Environmental Engineering; and explored related collaboration avenues within Southern California for local companies, universities, professional societies, government agencies, and the OCEC. Moreover, cross-disciplinary discussions and those research endeavors conducted in conjunction with the event enabled the foundation for one SAT IOC's future conference articles on sustainability in engineering that will be authored by the Springs of Dreams Corporation, a nonprofit organization in Southern California dedicated to enlightening society and enriching human lives through knowledge and education.



Mr. Glorim receiving his AIAA Joseph Freitag Sr. Award Certificate from Marion Pietsch, director of the Daimler Ausbildung and Training School, July 2017.

2017 Freitag Award Winner Honored

Roman Glorim is the winner of the 2017 AIAA Joseph Freitag Sr. Award. Mr. Freitag was a 1922 graduate of the Daimler Ausbildung and Training School in Stuttgart, Germany, and became a successful designer at the Sperry Gyroscope Company in New York. Through the AIAA Foundation, this award was created by Freitag's sons to memorialize their father and provide inspiration of what can be done with a Daimler education. Mr. Glorim completed his apprenticeship as an IT Electronic Systems Technician and was chosen by the faculty of the school to receive the award. He intends to complete his engineering studies in the field of Business Informatics and continue his professional career at Daimler AG.

AIAA Greater Huntsville Holds Young Professional Symposium

By Kyle Knox, *Co-Chair, AIAA Greater Huntsville Section Young Professionals Symposium*



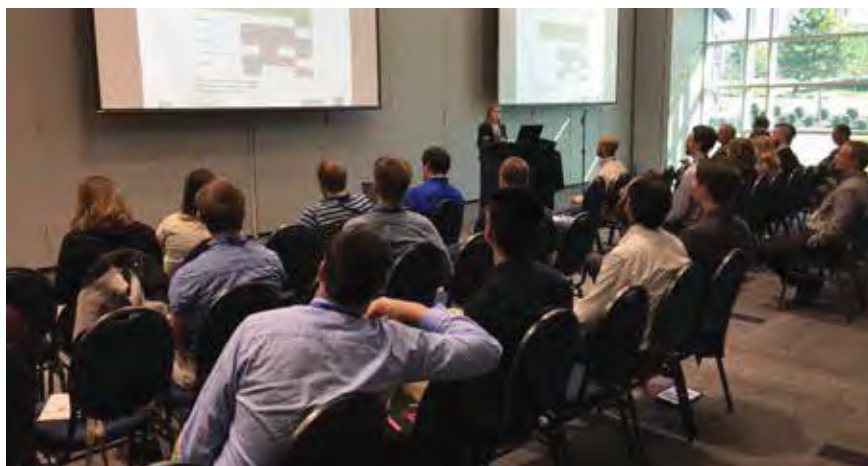
The 2nd annual AIAA Greater Huntsville Section's Young Professionals (YP) Symposium was held on 23–24 October, in Huntsville, AL. This year, the AIAA Greater Huntsville Section worked with NASA Marshall Space Flight Center and the American Astronautical Society to establish a connection between the YP Symposium and the Wernher von Braun Memorial Symposium (VBS). This mutually beneficial relationship encouraged YP involvement in VBS and allowed YPs more exposure to the senior executives generally in attendance at VBS.

The YP Symposium provided an opportunity for young professionals to give technical presentations to a group of peers and promoted opportunities for interaction, both technical and non-technical, with senior professionals in attendance. With 130 attendees, including 81 young professionals, this year's symposium was a huge success. Over 30 young professionals affiliated with 13 organizations spanning government, industry, and academia delivered technical presentations on a wide range of topics over both days. The first day's activities ended with an evening networking social sponsored by Jacobs.

In addition to technical presentations, the symposium included panel discussions and keynote speakers alongside professional development and networking opportunities. The first panel was on Unmanned Aerial Systems (UAS). This panel fostered an interesting discussion among UAS technical experts and program managers in the field of UAS. The second panel discussed the benefits of AIAA membership and

Above: Top presenters at the AIAA Young Professionals Symposium were recognized from each technical session by the AIAA Greater Huntsville Section planning committee. **From left to right:** Kyle Knox, Symposium Co-Chair, Kathryn Crowe (Systems Engineering), Tamara Statham (GN&C), Theron Price (Propulsion), Nishanth Goli (Modeling and Simulations), Adam Harris (Aerodynamics I), Joe Schoneman (Materials and Structures), Brian Kocher (Aerodynamics II), and Alexander Jehle, AIAA Greater Huntsville Section Vice Chair. Technical session winners not pictured included: Eric Bodlak (Propulsion), and Mark Becnel (Special Topics).

with a room full of engineers who hold a more technical focus. The second keynote speaker was Lt. Gen. James H. Dickinson, commanding general of the U.S. Army Space and Missile Defense Command/Army Forces Strategic Command and Joint Component Functional Command for Integrated Missile Defense. Lt. Gen. Dickinson shared his experience directing some of the most cutting-edge technology being developed in aerospace. He spoke of the



involvement. It included members of the Greater Huntsville Section who are involved in all aspects of AIAA ranging from the local student section to participation in AIAA forums as part of a technical committee.

Leaders from the local aerospace and defense communities delivered keynote speeches at this year's symposium. The first keynote speaker was Alicia Ryan, CEO of LSINC. Ryan shared insight into the business side of the industry

exciting opportunities in "Rocket City," insisting that YPs not only have big shoes to fill, but the responsibility of ensuring the next generation is ready to step up.

The final keynote speaker was Jody Singer, deputy director of NASA Marshall Space Flight Center. She spoke of the exciting work being done by NASA in preparation for the journey to Mars and emphasized the importance of the next-generation STEM workforce. Singer's keynote led directly into a



mentorship event, a highly anticipated addition to this year's symposium.

The mentorship event, sponsored by Aerojet Rocketdyne, provided the opportunity for attendees to sit down with senior professionals and learn from their experience. The 11 themed tables focused on various topics such as professional development, executive leadership, women in space, public speaking, entrepreneurship, and work/life balance. The mentors for this event included CEOs, program managers, presidents, and directors representing government, government contracts, and industry partners.

Immediately following the closing of the 2017 AIAA YP Symposium, attendees were invited to attend the Wernher von Braun Memorial Symposium welcome reception and student poster contest.

For more information on the AIAA YP Symposium, please visit www.aiaayps.org.



Nominate Your Peers and Colleagues!

Do you know someone who has made notable contributions to aerospace arts, sciences, or technology? Bolster the reputation and respect of an outstanding peer—throughout the industry **Nominate them now!**



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- Accepting online nominations monthly

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- Acceptance Period begins 15 December 2017
- Nomination Forms are due 15 April 2018
- Reference Forms are due 15 May 2018

Candidates for **FELLOW**

- Acceptance Period begins 1 April 2018
- Nomination Forms are due 15 June 2018
- Reference Forms are due 15 July 2018

Candidates for **HONORARY FELLOW**

- Acceptance period begins 1 January 2018
- Nomination forms are due 15 June 2018
- Reference forms are due 15 July 2018

"Appreciation can make a day – even change a life. Your willingness to put it into words is all that is necessary."

– Margaret Cousins

For more information on nominations: aiaa.org/Honors



News

AIAA Welcomes 2017–2018 Norris Space View Interns

By Lawrence Garrett, *AIAA web editor*

This fall AIAA welcomed our 2017–2018 Alexander R. Norris Space View Interns: **John (JT) Lewis**, of Prince Frederick, MD, and **Adam Boro**, of East Brunswick, NJ, both of whom are aerospace engineering majors in the University of Maryland’s Department of Aerospace Engineering in the James A. Clark School of Engineering. JT is scheduled to graduate in 2019, with Adam following in 2020.

Having begun their internships in September, JT and Adam are working 7–10 hours a week at AIAA Headquarters. Due to the demands of the program’s schedule, candidates for this year’s internship were again limited to students from accredited engineering programs in the Washington, DC, metro area.

JT explained why he was inspired to pursue an aerospace engineering career, saying that he’s been passionate about aerospace since he was a young boy, sparked by an early obsession with Star Wars. Over the summer, JT received a unique opportunity to add to his skills, working as an intern in power and propulsion at NAVAIR, helping analyze jet engine performance for the U.S. Navy. This experience made propulsion and power his primary interest moving forward. Adam said that his interest in aerospace engineering came from wanting to be involved in something that



John (JT) Lewis



Adam Boro

will have a “lasting impact, not only on the globe but on the [entire] universe.” Adam is most passionate about space “because of all the mysteries that are yet

to be discovered,” but he’s also interested in aviation and flight.

JT has been privileged to work on a number of fun and informative aerospace

CALL FOR PAPERS

ICNPAA 2018 World Congress: Mathematical Problems in Engineering, Sciences and Aerospace

3–6 July 2018

American University of Armenia (AUA), Yerevan, Armenia

On behalf of the International Organizing Committee, it gives us great pleasure to invite you to the ICNPAA 2018 World Congress: 12th International Conference on Mathematical Problems in Engineering, Aerospace and Sciences, which will be held at the American University of Armenia (AUA) Yerevan, Armenia.

Please visit the website, www.icnpaa.com, for all details. This is an AIAA, IFIP cosponsored event.

engineering projects while attending the University of Maryland, including a Rotor Design Project, an Over Sand Vehicle Project, and a Beam Design Project. He really enjoyed the Rotor Design Project because he was responsible for all of the testing and design of the rotors and it closely relates to his major.

Adam also has had the opportunity to work on a number of team projects at the University of Maryland. Currently, he serves as Media Team Leader on a project called Gamera, a manned-solar-powered helicopter “that has already set a world record for solar-powered flight.” He’s also part of the project’s Controls Team and Landing Gear Team, where he is working to innovate the aircraft’s landing gear by implementing new Piezo sensors. As the project’s Media Team Leader, Adam created the Gamera website, gamera.umd.edu, and has produced technical animations for the project’s promotional video.

Looking to their future careers, JT wants to remain in the Washington, DC, metro area, because of the abundant opportunities in aerospace that the region provides, adding that he believes he’ll likely end up back at

NAVAIR upon graduation. With Adam’s strong passion for space, he has made it his goal to pursue becoming an astronaut. He also would like to work on a team planning the habitation of Mars or an extraterrestrial object, calling it “a vital step for humanity.”

JT noted that his AIAA student membership has given him “many advantages academically and professionally,” citing the Institute’s online resources, technical documents, events for student branches, and a “head start toward networking with companies in the industry.” Adam also praised the value of his AIAA membership and what it offers in the way of career networking opportunities, social events, and technical publications, in addition to the availability of scholarships.

During their time at AIAA Headquarters, JT and Adam are being charged with an assortment of key tasks, one of which is conducting research and gathering important facts and figures about the aerospace and defense sector throughout United States. Using that information, the Institute plans to develop outreach documents that should prove beneficial to participants in the Insti-

tute’s 2018 Congressional Visits Day program, August is for Aerospace program, and other public policy activities.

Alexander R. Norris Space View Internship

Alexander “Al” Norris was an aerospace engineer whose career started prior to World War II as an aircraft design engineer and continued into the space age. He worked for storied names like McDonnell Douglas and Grumman Aircraft. He contributed to Navy development programs to design aircraft compatible for extreme polar environments. His work in the Navy earned him the U.S. Navy’s second highest civilian award for his expertise. His career culminated in work on the hatch and landing gear design of the Lunar Excursion Module. Norris’ daughter, Laurie B. Norris, contacted AIAA to propose a directed gift to the AIAA Foundation to fund two internships, and the Alexander R. Norris Space View Internship was established to honor her father’s career in aerospace and to help a new generation of engineers. Without her generosity this program would not be possible.

The full interview can be viewed at aiaa.org/MemberSpotlightOctober2017.

Section Supports Alabama’s Regional Future City Competition

By Dustin Poisson, *AIAA Great Huntsville Pre-College Outreach Director*

The K-12 STEM Outreach Committee would like to recognize outstanding STEM events in each section. Each month we will highlight an outstanding K-12 STEM activity; if your section would like to be featured, please contact Elishka Jepson (elishka.jepson@raytheon.com).

The AIAA Greater Huntsville Section supported Alabama’s Regional Future City Competition on 14 January 2017. The section sponsored a \$150 award for the team that displayed innovative aerospace technology in their city that improved the lives of their citizens. Twenty-three student teams gath-

ered under the Saturn V rocket at the Davidson Center to display their Future Cities to a number of judges. Everyone was impressed with the amount of creativity, innovation, and thought that these young students brought to the competition. They truly stood tall even in comparison to the Saturn V.

Team Sithena from D. A. Smith Middle School in Ozark, AL, took home the AIAA award with their blimp that provided surveillance for its citizens and notified local authority of any crime or danger. In addition, it assisted citizens with navigation around the city.

It’s good to know that the future generation has already started to consider taking existing technology and improving it for everyday use. Congratulations to Team Sithena, as well as the other 22 teams that participated in the Future City Competition.

Farhat Wins ASME Award



Charbel Farhat, an AIAA Fellow and technical expert in the design of complex aircraft structures, has been awarded the American Society of Mechanical Engineers (ASME) 2017 Spirit of St.

Louis Medal for sustained

theoretical and computational research contributions in the area of fluid-structure interaction, which have been applied to solving mission critical problems in aeronautics. His methodologies also have been applied in the automotive and marine industries, in addition to naval engineering, according to ASME.

Farhat, chair of the Department of Aeronautics and Astronautics at Stanford University, received the medal at the ASME International Mechanical Engineering Congress and Exposition. Farhat serves as director of the Army High Performance Computing Research Center at Stanford and is a member of the U.S. Air Force Scientific Advisory Board.

AFIT Student Branch Hosts Distinguished Lecturer

The Air Force Institute of Technology (AFIT) Student Branch recently hosted Tom Morgenfeld as a Distinguished Lecturer for branch members and members of the AIAA Dayton/Cincinnati Section. Morgenfeld gave a presentation on his years as an X-35 test pilot. In addition, the evening also included a poster session by sophomores at the University of Dayton. The students were given the design challenge “How can flight be used on a day-to-day basis by a common man?” Using the framework of Ideation, Disruption and Aha (IDA pedagogy), the students worked in teams and had six weeks to generate innovative ideas of how flight can make a tangible impact on society. They presented their results to the evenings’ attendees.



Members of the AIAA Dayton/Cincinnati Section viewing posters of University of Dayton students’ design challenge.



Distinguished Lecturer Tom Morgenfeld talking about his years as an X-35 test pilot.

Nominate Your Peers and Colleagues!

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PREMIER AWARD

- Daniel Guggenheim Medal

LECTURESHIPS

- Dryden Lectureship in Research
- Durand Lectureship for Public Service
- William Littlewood Memorial Lecture (due 15 January)

TECHNICAL EXCELLENCE AWARDS

- Aerospace Power Systems Award
- Air Breathing Propulsion Award
- Energy Systems Award
- George M. Low Space Transportation Award
- Haley Space Flight Award
- Hypersonic Systems and Technologies
- Propellants & Combustion Award
- Space Science Award
- Space Systems Award
- von Braun Award for Excellence in Space Program Management
- Wyld Propulsion Award

For Nomination Forms, please visit aiaa.org/AwardsNominations

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



Please submit the four-page nomination form and endorsement letters to awards@aiaa.org by 1 February 2018



Recently Presented AIAA Awards

AIAA Aerospace Communication Award



The AIAA Aerospace Communications Award was presented to **Stuart Linsky** at the 2017 Joint Conference of the AIAA International Communications Satellite

Systems Conference and the Ka and Broadband Communications Conference in Trieste, Italy, on 19 October. The award honored his “technical leadership, innovation and development of protected satellite communications systems.” Mr. Linsky is a vice president for Engineering and Global Product Development at Northrop Grumman Aerospace Systems.

Space Processing Award

The AIAA Space Processing Award was presented to **Dr. Mark Weislogel**



at the 33rd Annual Gravitational and Space Research meeting on 27 October in Renton, WA. The award was to honor his “decades of leadership in Space Shuttle and ISS zero-g fluids scientific experimentation and global public outreach via design and publicity of creative fluids activities onboard ISS.” Dr. Weislogel is a professor at Portland State University.

Obituaries

AIAA Associate Fellow Lamkin Died in September

Stanley L. Lamkin died 21 September. He was 70 years old.

Mr. Lamkin graduated from Old Dominion College in 1969 with a B.S. degree in Physics. He also received an M.S. degree (1974) and Ph.D. (1994) in Applied Physics. He retired from Hewlett Packard as a project manager specializing in programs for government and military customers in 2013.

A member of the AIAA Hampton Road Section, Lamkin was its vice chair and programs officer from 1993 to 1994. He was also the section chair from 1994 to 1995, and was the section's RAC representative from 1995 to 1996.

A Class of 1990 AIAA Associate Fellow, Lamkin was also recognized by Sigma Xi in 1990. In 1991, his work at NASA was recognized with a Superior Accomplishment Award, and he received an MVP from Hewlett Packard in 2005 and 2007 for his outstanding accomplishments.

AIAA Associate Fellow Brilliant Died in September

Howard M. “Mike” Brilliant died on 23 September.

Brilliant attended Baltimore Polytechnic Institute. He went to the University of Pittsburgh on an ROTC scholarship and received his Ph.D. from the University of Michigan.

He was an instructor at the U.S.

Air Force Academy, and he also taught engineering at Wright State University and Union Graduate College. He served 24 years in the U.S. Air Force including three tours at Wright-Patterson Air Force Base.

Brilliant went to work for GE in Cincinnati before moving to their Schenectady location in the research center and power systems.

He joined AIAA in 1964 and was chair of the Northeastern New York Section from 1994 to 1995, and served in several other section positions. He received a special service citation in 2007 for work on the Annual Tech Valley Engineering Symposium, and in 2004 he received a membership award for “increasing the section's membership by planning and implementing effective new member recruitment and retention campaigns.”

AIAA Associate Fellow Okauchi Died in September

Kinge Okauchi died on 26 September. He was 93 years old.

After finishing his first semester at San Jose State University, he was sent to an internment camp during World War II. After the war, he re-enrolled at the university. In 1949, he transferred to Stanford University, earning his Bachelor of Science degree and his master's degree in aeronautical engineering. He began work at the Naval Ordnance Test Station China Lake. Okauchi worked for 30 years in the Ballistics Division of the Research Department, Aeronautics Branch at Michelson Lab, retiring in 1980. He started his career early in the development of rocketry,

and later made the comment: “Nobody knew much about rockets back then and I didn't know much about rockets, so I fit right in.”

Okauchi was a 60-plus year member of the AIAA China Lake Section. He joined the American Rocket Society when he started working at China Lake in 1950. He was one of the charter members of the China Lake Section when AIAA was formed in 1963. During the section's 50th-anniversary ceremony in 2013, he was honored as one of the longest-serving members.

AIAA Associate Fellow Breuer Died in October

Delmar “DW” Breuer died on 13 October. He was 92.

Dr. Breuer earned a B.S. in Aeronautical Engineering from Iowa State University, an M.S. in Structures at the Missouri School of Mines, and a Ph.D in Aeronautical and Astronautical Engineering at Ohio State University. He served in the U.S. Navy from 1943 to 1946. His first position following college was as Instructor of Engineering Mechanics at Missouri School of Mines. In 1950, he was hired by North American Aviation and relocated to Los Angeles. In 1951, he was hired by the Air Force Institute of Technology, where he worked for the next 30 years. Breuer became a Department Head in 1958, and retired as Professor Emeritus of Aerospace Engineering on 1 January 1981.

An AIAA Associate Fellow, Breuer served as a member of the Survivability Technical Committee from 1989 to 1995.

FACULTY POSITIONS

The Department of Aerospace Engineering and Mechanics (AEM) at The University of Alabama invites applications for two tenure track and two non-tenure track faculty positions. One tenure track faculty position is in the area of unmanned aerial systems (UAS) and the other is in the area of space/astronautics. It is anticipated that successful candidates for the tenure track positions will join the faculty at the rank of Assistant Professor, although exceptional candidates may be considered for higher rank and tenure depending upon experience and qualifications. The two non-tenure track positions (one 9-month position and one 12-month position) will support AEM distance learning course offerings.

With 19 faculty members, the department enrolls approximately 475 undergraduate students in the ABET-accredited BSAE degree program and approximately 100 graduate students in the MS and PhD degree programs. The AEM Department is currently experiencing an era of unprecedented growth and expansion.

Applicants for the tenure track positions and for the 12-month non-tenure track position must have an earned doctorate degree in aerospace engineering, engineering science, mechanics, or a closely related field. Applicants for the 9-month non-tenure track position must have an earned MS degree in aerospace engineering, engineering science, mechanics, or closely related field.

Applicants are to submit a cover letter, CV, statement of research interests (for tenure track positions only), statement of teaching interests, and contact information for at least three professional references. Applicants should apply online at <http://facultyjobs.ua.edu>, (tenure track UAS requisition #0810803, tenure track space/astronautics requisition # 0810804, 12-month non-tenure track requisition # 0810805, and 9-month non-tenure track requisition # 0810806).

Review of applications will begin immediately and will continue until the positions are filled. Inquiries should be emailed to: aem@eng.ua.edu.

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



College of
Engineering
Aerospace Engineering and Mechanics



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Multiple Tenure Track Faculty Positions

The Department of Aerospace Engineering at Auburn University invites applications for multiple tenure-track and tenured faculty positions at the Assistant, Associate and Full Professor level. Areas of immediate interest include flight dynamics & control; orbital mechanics and space sciences; remote sensing; guidance, navigation and control; aerospace design and manufacturing; aerospace systems; unmanned aerial systems; and experimental fluid dynamics. Candidates with strong backgrounds in other areas relevant to aerospace engineering are also welcome to apply and will be fully considered as part of the current search.

Senior level candidates with a strong interest in providing mentorship and leadership to a young, enthusiastic and rapidly growing department are particularly encouraged to apply. Senior level candidates are also eligible for a Walt and Virginia Woltosz Professorship. All candidates will be expected to fully contribute to the department's mission through the development of a strong, nationally recognized, funded research program, teaching at both the undergraduate and graduate level, and 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. Candidates must have an earned doctorate in aerospace engineering, mechanical engineering or a closely related field.

Candidates can login and submit a cover letter, CV, research vision, teaching philosophy, and three references at:

<https://aufacultypositions.peopleadmin.com/postings/2454>. 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, 2017 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/>

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



AEROSPACE ENGINEERING

TEXAS A & M UNIVERSITY

Texas A&M is located in the twin cities of Bryan and College Station, with a population of more than 255,000, and is conveniently located in a triangle formed by Dallas, Houston and Austin. With over 600 tenured/tenure-track faculty members and more than 16,000 students, the College of Engineering is one of the largest engineering schools in the country. The college is ranked 7th in graduate studies and 8th in undergraduate programs among public institutions by *U.S. News & World Report*, with seven of the college's fourteen departments ranked in the Top 10.

The vision of Aerospace Engineering at Texas A&M University is a nationally and internationally renowned program that attracts the world's top faculty and students and promotes a passion for learning and applying the knowledge of science and engineering to lead in providing solutions to the most challenging problems in the field. The thirty-seven tenured/tenure-track faculty include six members of the National Academy of Engineering and ten endowed positions. The student body is made up of 600 undergraduate and 140 graduate students. The department is committed to an extensive suite of facilities to enable leading research. The graduate and undergraduate programs are ranked 4th and 7th, respectively, among public institutions by U.S. News & World Report.

As part of a major growth initiative, we invite applications for multiple tenured or tenure-track faculty positions at the assistant, associate, or full professor levels. Resources will be provided to facilitate the initiation of independent research activities and opportunities exist for collaboration with leading Texas A&M faculty in related areas. We are particularly interested in faculty with expertise in:

- **Aerodynamics and Space Situational Awareness.** Orbit dynamics, attitude dynamics, space robotics, guidance, navigation and control of space vehicles, low thrust trajectory optimization and space mission design (Position #FVN1442014)
- **Autonomous and Robotic Systems.** Multi-body dynamics and control design, robotics, tensegrity systems. (Position #FVN1452014)
- **High Speed Fluid Dynamics.** Laser diagnostics, flow control, experimental methods, plasma aerodynamics and energy conversion. (Position #FVN1412014)
- **Human Spaceflight Systems.** Spacesuit systems and human anthropometrics, aerospace materials (e.g. woven fabrics), embedded sensors, structural dynamics, partial gravity fluid physics, environmental life support, displays and controls, and digital human modeling (Position #FVN1422014)

The successful applicants will be required to teach; advise and mentor graduate students; develop an independent, externally funded research program, participate in all aspects of the department's activities, and serve the profession. Applicants must have an earned doctorate in aerospace engineering or a closely related science discipline. Strong written and verbal communication skills are required. Applicants should consult the department's website to review our academic and research programs (<https://engineering.tamu.edu/aerospace>).

Applicants should submit a cover letter, curriculum vitae, teaching statement, research statement, and a list of four references (including postal addresses, phone numbers and email addresses) as part of the application package to be submitted for one of the above positions at www.tamengineeringjobs.com. Full consideration will be given to applications received by January 1, 2018. Applications received after that date may be considered until positions are filled. It is anticipated the appointment will begin fall 2018.

The members of Texas A&M Engineering are all Equal Opportunity/Affirmative Action/Veterans/Disability employers committed to diversity. It is the policy of these members to recruit, hire, train and promote without regard to race, color, sex, religion, national origin, age, disability, genetic information, veteran status, sexual orientation or gender identity.

Faculty Opening

STANFORD UNIVERSITY

DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

Stanford | ENGINEERING

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, 2018.

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.

FACULTY POSITIONS

AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AFB, DAYTON OH

The Department of Aeronautics and Astronautics seeks applicants for two tenure-track Aerospace Engineering faculty position (preferably at the assistant or associate professor level) and one non-tenure-track Aerospace Engineering faculty position. The first tenure track position is desired in the area of Aeronautical Engineering, namely Hypersonics, Air Breathing Propulsion or Aerodynamics. The second tenure-track position is sought in the area of Astronautical Engineering, namely Spacecraft Design and Controls. While expertise in these disciplines will be given preference, other expertise will be considered. The non-tenure-track position is targeting Hypersonics and/or Aerothermodynamics. In addition to an earned Ph.D. in Aeronautical Engineering, Astronautical Engineering, Mechanical Engineering or a related field, candidates for all three positions should have demonstrated or show a potential ability in teaching at the graduate level and in conducting independent research for the Air Force and other government agencies. Good communication skills, both oral and written, are essential. Applicants must be U.S. citizens. Applicants must currently possess or be able to obtain/maintain a TOP SECRET clearance if applying for a Hypersonics position or a SECRET clearance if applying for any other position. If selected, applicants must produce proof of citizenship at time of appointment. Link to full posting can be found at <https://www.usajobs.gov>

The Department offers both M.S. and Ph.D. degrees in Aeronautical Engineering, Astronautical Engineering, Space Systems and Materials Science. The Department has several state-of-the-art computer and experimental laboratories. Interested candidates must apply for the position through USAJOBS (see link above). Questions regarding the position may be addressed to:

Dr. Brad S. Liebst, Professor and Head,
Department of Aeronautics and Astronautics, Air Force Institute of Technology
AFIT/ENY
2950 Hobson Way, Wright-Patterson AFB, OH 45433-7765
Phone: (937) 255-3069, e-mail: Bradley.Liebst@afit.edu

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MEMBERSHIP MATTERS

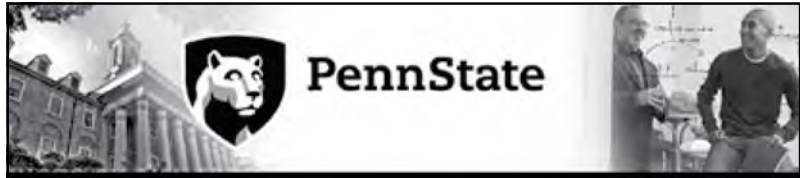


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- 4. Publish Your Work –** If you are searching for the best place to publish or present your research, look no further! AIAA has five targeted **forums**, eight specifically focused **journals**, and a number of co-sponsored conferences to choose from. Find your peers, publish your work and progress in your career!
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16-1302

www.aiaa.org



Tenure Track Position in Aerospace Vehicle Design

The Department of Aerospace Engineering at The Pennsylvania State University invites nominations and applications for a full-time, tenure-track faculty position starting in Fall 2018. The position is intended for the rank of Assistant Professor, although exceptional applicants at more senior ranks may also be considered.

Outstanding candidates working in all subject areas relevant to aerospace engineering will be considered, with special emphasis in the area of vehicle design, particularly towards the design of novel aircraft, rotorcraft or spacecraft enabled by new technologies, new business models, and/or pervasive on-board sensing and computation. Applicants should articulate their plans to setup a research program in which new methods of design and vehicle integration will attract outside research sponsorship, contribute to the aerospace industry, and result in published research findings. Further, applicants should describe how they will collaborate with the disciplinary strengths already in place within the department in support of cross-disciplinary collaborative research and in support of the department's undergraduate and graduate programs.

The Department of Aerospace Engineering at Penn State is strongly committed to our educational mission. Successful candidates should demonstrate interest in teaching undergraduate and graduate courses.

Applicants must have an earned doctorate in aerospace engineering or a related field. Responses received before January 15, 2018 are assured full consideration, but the search will remain open until the position is filled. Applicants should submit electronically a single pdf file that contains a cover letter, a CV, a statement of research and teaching interests, and the names and contact information for at least three references.

The Department of Aerospace Engineering enjoys an excellent international reputation in aeronautics and astronautics. The department currently has 19 full-time faculty members, more than 250 juniors and seniors, and more than 120 graduate students. Annual research expenditures exceed \$6 million.

Penn State at University Park is a land-grant institution located within the beautiful Appalachian mountains of central Pennsylvania. State College and nearby communities within Centre County are home to roughly 100,000 people, including over 40,000 students, and offer a rich variety of cultural, recreational, educational, and athletic activities. State College is a wonderful community in which to raise a family and has an excellent public school system.

We especially encourage applications from individuals of diverse backgrounds, as the department seeks to grow in the diversity of its faculty.

Apply online at <http://apptrkr.com/1096401>

CAMPUS SECURITY CRIME STATISTICS: For more about safety at Penn State, and to review the Annual Security Report which contains information about crime statistics and other safety and security matters, please go to <http://www.police.psu.edu/clery/>, which will also provide you with detail on how to request a hard copy of the Annual Security Report.

Penn State is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to all qualified applicants without regard to race, color, religion, age, sex, sexual orientation, gender identity, national origin, disability or protected veteran status.

1917

1942



Dec. 3 The French government agrees to transfer fighter squadron SPA 124 to the U.S. Army Air Services. SPA 124 is better known as the Lafayette Escadrille and is comprised of American pilots fighting under French command. Most other Americans flying for France through the Lafayette Flying Corps are also offered the opportunity to transfer to new American units. Most of them transfer while some prefer to stay with their units. David Baker, *Flight and Flying: A Chronology*, p. 104.

Dec. 26 A simulated altitude chamber for aircraft is tested for the first time at the U.S. Bureau of Standards for the National Advisory Committee for Aeronautics. It is able to test engine performance in a one-third atmosphere environment. E.M. Emme, ed., *Aeronautics and Astronautics 1915-1960*, p. 7.



Dec. 1 Germany's Heinkel Aircraft Works celebrates its 20th anniversary. Ernst Heinkel, its founder and principal designer, concentrated on sporting and seaplane machines for the company's first decade, then in 1933 began building military aircraft. Examples include Heinkel He 51 fighters, first used in combat in the Spanish Civil War in 1936; the He 219 twin-engined night fighter; and the He 111 and He 177 bombers. Heinkel also produced revolutionary aircraft such as the experimental, turbojet-powered He 178 and He 280 twin-engined turbojet powered fighter. *The Aeroplane*, Dec. 11, 1942, p. 674.

Dec. 1 Gen. Ira Eaker replaces Gen. Carl Spaatz as commanding general of the 8th Air Force when Spaatz flies to Algeria to serve as an air adviser to Gen. Dwight Eisenhower, theater commander and acting deputy commander in chief for air of the Allied forces in Northwest Africa. K.C. Carter and R. Mueller, compilers, *The Army Air Forces in World War II*, pp. 64-65.

Dec. 2 A Republic P-47 Thunderbolt reportedly reaches a world speed record of 725 mph (1,167 kph) in a power dive; the record, however, is unofficial. *The Aeroplane*, Dec. 11, 1942, p. 674.

Dec. 2 The first nuclear chain reaction is accomplished at the University of Chicago. Carried out in the greatest secrecy, it will lead to the atom bomb. E.M. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 44.



Dec. 4 The Army Air Forces use Consolidated B-24 Liberators to make their first aerial assault upon Italy, bombing the Italian fleet and docks at Naples. Numerous harbor installations, a railroad yard, and three or four vessels, including a battleship, are struck. K.C. Carter and R. Mueller, compilers, *The Army Air Forces in World War II*, p. 65.

Dec. 8 Two new U.S. aircraft carriers, the USS Bunker Hill and the USS Belleau Wood, are launched on the first anniversary of the nation's entry into the war. Both vessels were designed as 10,000-ton cruisers. *The Aeroplane*, Dec. 18, 1942, p. 701.

Dec. 9 A special report on the first 1,100 bombers deployed by the 8th Air Force between August and November justifies high-level daylight precision bombing. K.C. Carter and R. Mueller, compilers, *The Army Air Forces in World War II*, p. 67.



Dec. 17 The annual Wright Brothers Lecture, delivered each December on the anniversary of the Wright brothers' first flight, is presented by Edmund Allen of Boeing Aircraft at Columbia University under the auspices of the Institute of Aeronautical Sciences. He speaks on "Flight Testing for Performance and Stability," describing the development of modern flight testing techniques from the viewpoint of an aero-dynamicist and aeronautical engineer. *Aero Digest*, January 1943, p. 384.



Dec. 27 The Kawanishi NIK1-J Shiden naval fighter completes its first flight. Code-named "George," the Shiden subsequently is assigned to the

Southwest Pacific theater by the Japanese and proves itself a deadly adversary, comparable to the Grumman F6F Hellcat. Rene Francillon, *Japanese Aircraft of the Pacific War*, pp. 320-329.

During December 1942

The Army Air Forces conduct the first flight tests of a full-pressure high-altitude flight suit at Eglin Field, Florida. E.M. Emme, ed., *Aeronautics and Astronautics 1915-60*, p. 44.



Germany's Me 264 very-long-range bomber makes its first flight. Since it is meant for use against the U.S., it is nicknamed the "Amerika Bomber" and has a range of 14,500 kilometers. Two of these giant aircraft are completed but never enter service. The first eventually flies in a special transport squadron; the second is destroyed on the ground by an Allied bombing attack. J.R. Smith and A. Kay, *German Aircraft of the Second World War*, pp. 549-552.

1967

Dec. 4 The European Launch Development Organization's Europa 1 rocket is launched from the Woomera Rocket Test Range in Australia but is automatically destroyed after the French Coralie second stage fails to ignite. The vehicle's first stage British Blue Streak rocket performed satisfactorily. **New York Times**, Dec. 6, 1967, p. 16.

Dec. 6 Herbert Friedman of the U.S. Naval Research Laboratory receives the 1967 Rockefeller Public Service Award of \$10,000 from Princeton University for his outstanding work in rocket astronomy that included revealing the strength and patterns of ultraviolet and X-rays from altitudes of 80 kilometers and above, using a variety of sounding rockets. **Science**, Dec. 29, 1967, p. 1655.

Dec. 8 U.S. Air Force Maj. Robert Lawrence Jr., the first African-American selected for a mission of the Manned Orbiting Laboratory in the U.S. space program, is killed during a routine training flight while flying an F-104 aircraft at Edwards Air Force Base, California. Born in 1935, Lawrence earned a Ph.D. in physical chemistry from Ohio State University and became an Air Force test pilot. He tested such aircraft as the X-15, and due to the flight maneuver data he acquired he was cited by NASA as greatly contributing to the development of the space shuttle. The Manned Orbiting Laboratory program is later canceled. **Washington Post**, Dec. 9, 1967, p. A-1.

Dec. 12 The first U.S. hybrid (combination liquid fuel/solid rocket) propulsion system designed for operational use makes its first test flight at Eglin Air Force Base, Florida. The hybrid rocket engine, developed by the United Technology Center (later the UTC Chemical Systems Division), is fitted into a modified supersonic target missile and designed for eventual deployment in the Sandpiper, an advanced, high-performance target missile that simulates a variety of potential missile and aircraft threats. UTC's propulsion system offers a wide and adjustable range of thrust levels from 264 to 22,221 newtons. **Aviation Week**, Jan. 8, 1968, p. 24.



Dec. 14 Igor Sikorsky, the famous Kiev-born aviation pioneer and designer of the world's practical helicopter, is honored with the Wright Brothers Memorial Trophy at the annual Wright Brothers Memorial Dinner in Washington, D.C. **Aviation Week**, Oct. 23, 1967, p. 23; **Flight International**, Dec. 28, 1967, p. 1056.



Dec. 15 A full-power test is completed under the U.S. Nuclear Engine for Rocket Vehicle Application, or NERVA, program at NASA's Jackass Flats, Nevada, installation. The test of the Aerojet-General NRX-A6 reactor, operating at about 1,100 megawatts, totals 70 minutes and paves the way for the next phase of the NERVA engine development program early in the coming year when a ground-test version of a nuclear rocket engine will be fired. **Aviation Week**, Dec. 25, 1967, p. 23; and Jan. 15, 1968, p. 97.

Dec. 17 The U.S. Air Force's RF-111A reconnaissance aircraft completes its first flight from Carswell Air Force Base, Texas. The aircraft's cameras and infrared and radar sensing equipment are also tested in the three-hour flight. **Department of Defense Release** 1182-67; **Aviation Week**, Dec. 25, 1967, p. 16.



Dec. 20 France's first variable-sweep-wing jet aircraft, the Mirage G, flies at 2,414-kph in its public debut at Istres, France. **Washington Post**, Dec. 21, 1967, p. A-31.

Dec. 27 Boeing delivers its first 737 jet to a customer (Lufthansa German Airlines) in a ceremony at Boeing's plant at Seattle; the second one is delivered to United Airlines on Dec. 29. The Boeing 737 series subsequently becomes the best-selling jet commercial airliner in history. **Aviation Week**, Jan. 1, 1968, p. 30.

Dec. 27 The Soviet Union launches the Cosmos 198 satellite into a circular orbit around Earth; it is later revealed to be its first maneuverable satellite. On the following day the satellite is directed by ground signals to re-ignite its rocket motors that move it into a much higher circular orbit. Launched by a Cyclon 2 vehicle from the Baikonur Cosmodrome, the Cosmos 198 is a nuclear-powered ocean reconnaissance satellite. **Flight International**, Jan. 25, 1968, p. 135.



Dec. 29 Leo White, the pilot, author, aviation historian and Royal New Zealand Air Force official wartime photographer, dies at 61. After leaving the RNZAF in 1945, he established Whites Aviation and launched a number of periodicals including Whites Aviation, New Zealand Flying and the annual Whites Air Directory. **Flight International**, Jan. 18, 1968, p. 76.

1992



Dec. 2 Under the command of U.S. Navy Capt. David Walker, the space shuttle Discovery is launched into orbit carrying a classified satellite for the Pentagon. It is widely believed that the mission is intended to monitor troop movements in Eastern Europe, Asia, and the Middle East, following the recent collapse of the Soviet Union and its effects on the country's military partners around the world. **NASA Astronautics and Aeronautics, 1991-1995**, p. 278.

Dec. 28 Lockheed announces that it has formed a joint venture with the Russian firm Krunichev Enterprise to market commercial satellite launches on the Russian Proton booster. It is hoped that this will help lower the cost of placing satellites into orbit and improve relations between the two former rival countries. **NASA Astronautics and Aeronautics, 1991-1995**, p. 286.

During December

The European Space Agency's European Remote Sensing Satellite-1, or ERS-1, demonstrates its ability to detect the movements of features as small as 1 centimeter across on Earth's surface, which could be a great advance in the forecast of earthquakes in monitoring plate tectonics. ERS-1 was launched on July 17, 1991. **Aviation Week**, Dec. 14-21, 1992, pp. 50-52.

JOËL BOUDREAU, 31

Conceptual design engineer at Bombardier



Growing up next to an airport in Quebec City, Joël Boudreau was fascinated by the airplanes he watched taking off and landing. That interest continued at the École Polytechnique de Montréal, where Boudreau decided that aerospace engineering could help him turn advanced technology into something concrete and useful. In 2010, Boudreau went to work for Bombardier, initially joining the Advanced Design group and then in 2013 working with other engineers to evaluate, optimize and track the performance of Bombardier's new C Series narrow-body airliners. In October, Airbus announced plans to acquire a majority stake in the C Series program in part to avoid U.S. import duties by manufacturing the jets in Mobile, Alabama.

How did you become an engineer?

What sparked my initial interest in engineering was my curiosity in trying to understand how things worked. That happened from a very young age. Lego [the children's construction game] was probably a big contributor to my interest. I was raised next to an airport in Quebec City, so airplanes were something common for me to see but always fascinated me at the same time. In college, I had the opportunity to study in Montreal, home of the world's third-largest aerospace cluster. At the École Polytechnique de Montréal, I earned a bachelor's degree in mechanical engineering with a specialization in aerospace. I also did an internship at Bell Helicopter in Mirabel, Canada. In college, I had teachers who worked at Bombardier. A teacher from my Aircraft Conceptual Design class told me of an opening in his department, Bombardier's Advanced Design group. I got the position working on the initial assessment of future development projects. A few years later, with the C Series getting closer to its first flight, I joined the Aircraft Performance group. Flight testing of a brand-new aircraft doesn't happen often. I took the opportunity and the great challenge that came with it. I was involved in defining tests, briefing the flight crews, monitoring safety and recording telemetry. The testing involved stalls, takeoffs in different conditions (including single-engine operation), landing and measurement of in-flight drag. Most of my work was done in the C Series Mirabel facility, but I also traveled to our main Bombardier Flight Test Center in Wichita, Kansas, as well as other locations to support various tests.

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

Commercial and business aircraft are always trying to increase their range capability, but that is not a technical challenge anymore because most recent aircraft are efficient enough to fly longer routes economically. The next barrier will be to provide the passengers with the ability to be comfortable in a given aircraft for an extended time, 17 hours-plus. Aircraft manufacturers will have to either improve passenger comfort or increase the aircraft's speed. I believe that by 2050, we should see supersonic flights making a comeback in business aviation. Many small startup companies are looking at different prototypes of supersonic business aircraft but no major aircraft manufacturer has announced anything so far. I would expect the major manufacturers to get into this challenge if startups become serious contenders. For commercial aviation, I believe that we should slowly see major manufacturers trying to improve the cabin experience while increasing the cruise speed. ★

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