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AEROSPACE
★ ★ ★ AMERICA ★ ★

2016
YEAR IN REVIEW

AIAA
Shaping the Future of Aerospace

11 ★ ★ ★ AEROSPACE AMERICA ★ ★ DECEMBER 2016 aerospaceamerica.org

THE YEAR IN REVIEW

The most important developments as described by AIAA's technical and program committees

NASA

▲ **NASA's Juno** spacecraft closes in on Jupiter in late August, making a pass at the giant planet and showing in ever-sharper detail the north polar region.

AEROSPACE AMERICA

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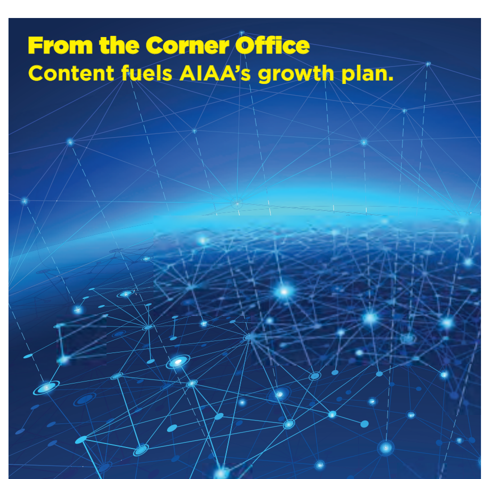
AIAA
Shaping the Future of Aerospace

YEAR IN REVIEW

DEPARTMENTS



Blue Origin

▲ **Blue Origin's New Shepard booster** executes a controlled vertical landing.

The year of living tenaciously

As a magazine editor, I've never been more eager to chronicle and explore the future than I am now. One reason is the 2016 work described in this special issue, from development of clean aircraft technologies to efforts by Blue Origin and SpaceX to master rocket reusability.

Tenacity is the word that comes to mind when I review the articles in this issue. Last year, when we produced the year-end issue, Blue Origin had not yet reused its New Shepard rocket and SpaceX was 0 for 2 on attempts to land a Falcon 9 first stage. Now, Blue Origin has proved it can fly its New Shepard booster again and again, and SpaceX has landed a Falcon 9 first stage on land and at sea on a drone ship. 2017 promises even greater advances.

There's another reason for eagerness. Aerospace America stands ready to explore the big changes promised by the incoming administration of President-elect Donald Trump. We'll examine those changes as they relate to your work and the aerospace community. We'll do that in the same manner we always do: by putting aside assumptions and exploring issues in a no-nonsense, in-depth way, always with an eye toward technology and science.

We'll want to see how the new administration treats funding for the satellites and aircraft that gather climate data. We'll look at related issues, such as the potential for global regulation of greenhouse gas emissions by satellites, and whether an approach like that can succeed without the U.S.

We'll want to learn whether a Trump administration, and a Republican-controlled Congress, can clear the way for solutions to tracking airliners, and whether expenditures on clean aviation and supersonic transport will continue. The Trump campaign gave some clues in our "10 questions for the candidates" article in May. The campaign said the impact of aviation on climate change is "minimal" and that resources must always "advance and protect" U.S. interests. On supersonics, Trump said: "The free market will determine if supersonic air transport is feasible."

In the space realm, much of what NASA does right now centers on the vision of getting human explorers to Mars in the 2030s, and honing skills at an asteroid that would be dragged within reach of astronauts. That idea will have to compete for resources against a proposal favored on Capitol Hill to robotically explore Jupiter's moon Europa, which could harbor life of some kind under its ice.

We don't know whether a Trump administration will share the excitement for Mars and Europa. In the "10 Questions" article, the Trump campaign said human exploration depends on the country's "economic state."

We're ready to work tenaciously on these and many other topics. ★

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

It's All About the Content

"It's all about the content." It seems like that buzz-phrase comes up time and time again regardless of whether discussing websites, training materials, conferences and symposia, or print or electronic media. Buzz-phrase or not, content truly is the distinguishing factor between being relevant or not, and the ability of an organization to generate interest in their products. At AIAA, we are ever mindful that our members and people in the aerospace industry engage with the Institute because they recognize the content of our programming and products as being topical and relevant. Our content drives members and other aerospace professionals to engage with AIAA in order to be informed, educated, and connected, and is seen as necessary for their professional development and the needs of their employers. Furthermore, the participation of AIAA members in the identification and evaluation of what content is important to aerospace professionals is vital to a viable, healthy, and ultimately sustainable Institute.

The Institute has recently gone through an exercise that identified societal and technology trends that are affecting or will soon affect the aerospace industry and workforce in significant ways. A few areas were identified as critical for the Institute to move quickly and smartly to develop programming and products that our membership and others most need and find most helpful. The 2017 Growth Plan is focused in five areas: unmanned aerial systems, the commercialization of space, cybersecurity, advanced manufacturing, and electric aircraft/propulsion.

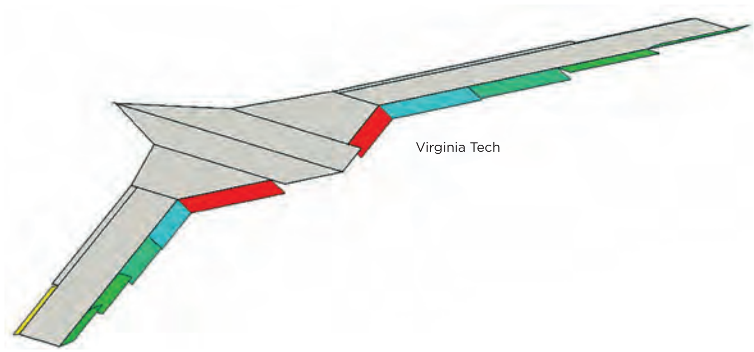
Already we've successfully initiated programming at various forums in these areas. At the AIAA AVIATION Forum in June, we held the first DEMAND for UNMANNED UAS symposium. The event attracted 275 individuals, 30% of whom reported that they would not have otherwise attended the AVIATION Forum. A hybrid electric propulsion workshop was held at the AIAA Propulsion and Energy Forum in July where we engaged with researchers from government labs and from academia who are working on the peripheral technologies of energy storage and power distribution. The workshop participants learned how the state of the art in these technologies affect what potential design and development approaches for hybrid electric propulsion systems for all classes of air vehicles. A follow-up activity, an Electric Aircraft Workshop and Expo, will be held at the 2017 AIAA AVIATION Forum. Finally, at the AIAA SPACE Forum in September, we held the Space Commercialization Executive Summit, where leaders in the space industry gathered to identify the hurdles confronting the successful commercialization of space and the solutions required to clear those hurdles.

So what can you do to help and how can you get involved? The answer is, we want our members to engage in every step of the process, as it best aligns with individual interests and time. For example, we are working with the Emerging Technology Committee to focus on its chartered purpose to identify emerging trends and technologies around which AIAA needs to develop content, programming, and products. To get involved you don't have to be a futurist to make a contribution, only to have a curiosity about technology and how and why these technologies will affect aeronautics, aviation, and space.

The Growth Plan activities need champions and, more importantly, they need doers. I encourage you to get involved through the appropriate Technical Committee or Program Committee. This is your opportunity to influence and guide the creation of content to be delivered across AIAA's forums, publications, and other programs. An excellent example is the Transformational Flight Program Committee's leadership of the development, programming, and execution of the upcoming Electric Aircraft Workshop and Expo. Another is the Unmanned Systems Program Committee's help in organizing and developing programming at both the inaugural and the 2nd DEMAND for UNMANNED. Conversely, some committees do not currently have enough members to make the type of difference that they could. For example the Space Exploration Program Committee in particular could use bright and energetic members who desire to make a difference in the commercialization of space.

Get involved, make a difference. Whether you view this as an opportunity to payback an industry or a mentor that has enabled you to have a fulfilling career, or as an opportunity to pay it forward to the next generation of aerospace professionals, it is only through your involvement that AIAA will continue to be a relevant and enduring institution and to thrive in this ever-changing industry. ★

James Maser, AIAA President



▲ **Multidisciplinary design optimization** was used to design the internal structure of an unmanned air system to be built and tested as part of NASA's Performance Adaptive Aeroelastic Wing Program. Shown is the optimal internal structural layout of the unmanned system.

Design progress on many fronts

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.

The year brought advances in many aspects of multidisciplinary design optimization.

It saw the release of a new **OpenMDAO** version from the NASA Glenn Research Center, with contributions from the University of Michigan's MDO Lab, ONERA Systems Design and Performance Evaluation Department, Brigham Young University's Flow Lab, the National Renewable Energy Laboratory in Golden, Colorado, and the Technical University of Denmark. The latest developments extend gradient-based optimization with analytic derivatives to a broad class of multidisciplinary problems. One of the developed test-bed problems, **OpenAeroStruct**, is a low-fidelity aerostructural optimization suitable for educational and research purposes. Another test bed is large-scale wind farm layout and yaw-control optimization to maximize energy production.

Tackling computational cost

Surrogate and reduced-order modeling methods are an important element in reducing the costs of solving MDO problems. Increasing attention is being given to **multifidelity MDO**, which leverages lower-fidelity models and surrogates together with high-fidelity analysis. McGill University in Montreal developed novel methods, algorithms and error metrics for direct search, surrogate-assisted optimization with diverse applications including design of music instruments. Santa Fe Institute in New Mexico is investigating recurrent neural networks to find reduced-order models of high-dimensional dynamical systems, and new multifidelity Bayesian optimization methods. MIT developed multifidelity methods for design under uncertainty, including uncertainty propagation through coupled multidisciplinary systems and optimal allocation of evaluations among multiple surrogate models.

Multidisciplinary coupling

Multidisciplinary problems present significant challenges to analysis and design methods, due to coupling between disciplines. Texas A&M is developing efficient model discrepancy propagation methodologies for coupled systems. MIT developed a graph-theoretic method for optimal decoupling of multidisciplinary systems. The Multiscale Multiphysics Design Optimization lab at the University of California, San Diego, and Cardiff University in Wales developed **multiscale topology optimization** for simultaneously optimizing a structure and the microscopic topology of the architected material. This yields a design solution that can be readily manufactured by additive manufacturing with optimally tailored material properties. The University of Illinois Engineering System Design Lab investigated generative design for additive manufacturing and new intelligent structure design strategies that simultaneously tailor freeform structural geometry and distributed control. They applied these strategies to precision spacecraft slewing and pointing. The Systems Optimization Lab developed a conceptual whole jet engine MDO model in collaboration with Chalmers University of Technology in Sweden and GKN Aerospace Engine Systems.

The Air Force Research Laboratory MSTC-Virginia Tech-Wright State University Collaborative Center on Multidisciplinary Science did research that included **topology optimization** of multifunctional structures using multiscale analysis; a new quasi-Newton algorithm QNSTOP for stochastic and global optimization; and nonintrusive aeroelastic shape sensitivity analysis.

Exploring multidisciplinary technologies

NASA's Advanced Air Transport Technologies project is exploring multidisciplinary technologies through passive and active aeroelastic tailoring methods for subsonic transport wingbox structures, including tow-steered composites, curvilinear stiffeners, through-thickness topology optimization, and variable-camber continuous trailing edge flaps. NASA is collaborating with Aurora Flight Sciences of Virginia to build a **tow-steered wingbox** for structural testing. The University of Michigan optimized the tow-steered design using high-fidelity aerostructural optimization, and Georgia Tech is performing topology optimization of the wingbox. The Multidisciplinary Analysis and Design Center for Advanced Vehicles at Virginia Tech is developing a computational design environment for MDO of subsonic and supersonic aircraft wings whose designs are expected to include curvilinear spars and ribs enabled by additive manufacturing. ★

Incorporating uncertainties in aircraft design

BY QIQI WANG

The **Non-Deterministic Approaches Technical Committee** advances the art, science and cross-cutting technologies required for applying non-deterministic modeling and analysis to aerospace systems.

Aircraft design can be viewed as optimizing a complex system under uncertainty. One approach to managing this difficult task is to hierarchically decompose the problem, both along disciplines such as aero, structures and propulsion and along subsystems such as wing, empennage and fuselage. Although this **decomposed multilevel optimization** approach can offer more efficient solutions, effectively incorporating uncertainties has proven to be challenging. Mississippi State University is tackling this challenge through variations of the decomposition and internal subproblem coordination, especially for problems involving multiscale systems.

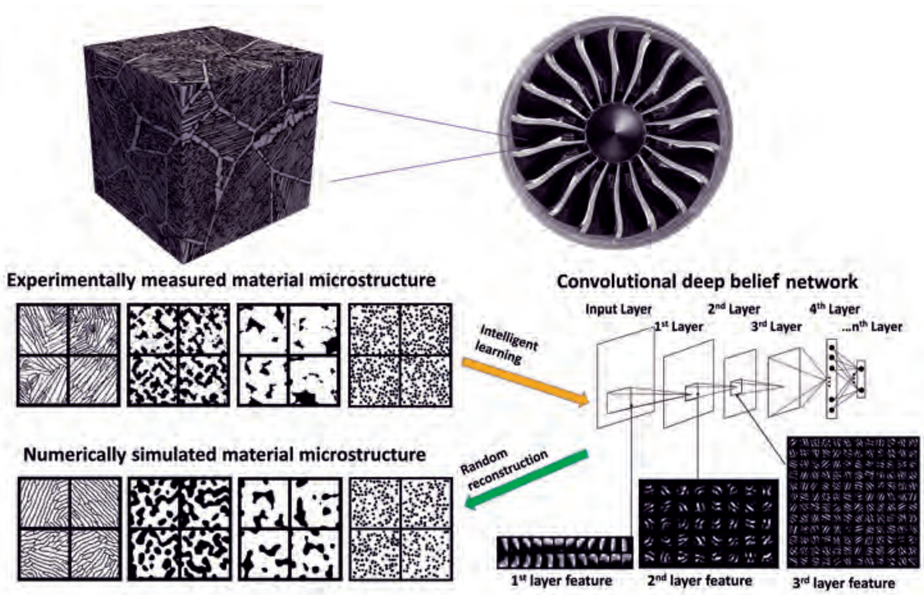
Goal-oriented design, such as designing a jet for a specific type of mission, can benefit from tools of uncertainty quantification. In such design scenarios, the goal or the mission poses constraints such as endurance, observability and maneuverability. Designs with a maneuverability constraint must consider **flutter**, which can be modeled using either a detailed and expensive flow solution or a simplified model. Such different levels of fidelity are often available in modeling each physics. Wright State University in Ohio is using uncertainty quantification to decide the fidelity for each physics, given the goal of the design and available computational resources.

Integrated computational material engineering can change how aerospace engineers design and manufacture material. Arizona State University is using deep learning to understand how structural properties of a material depend on its manufacturing process. It used **Convolutional Deep Belief Network**, a technique used in state-of-the-art voice recognition, to predict what a material looks like at multiple scales. Their outputs are multichannel binary images that represent possible spatial patterns of a material. The resulting images help to accurately reconstruct stochastic microstructure of materials, such as the Ti-6Al-4V alloy widely used in the aerospace industry.

In June, Sandia National Laboratories held a workshop on **"Complex Systems Models and Their Applications: Toward a New Science of Verification, Validation and Uncertainty Quantification."** The workshop illuminated research opportunities that intersect with two important Sandia communities: the complex systems modeling community, and the verification, validation and uncertainty quantification community. The overarching research opportunity is how to quantify the credibility of knowledge gained from complex systems models, such as cyber systems, climate and economics, the electric grid, and disease spread or natural disasters with human reactions. The workshop established a long-term research agenda for answering these questions.

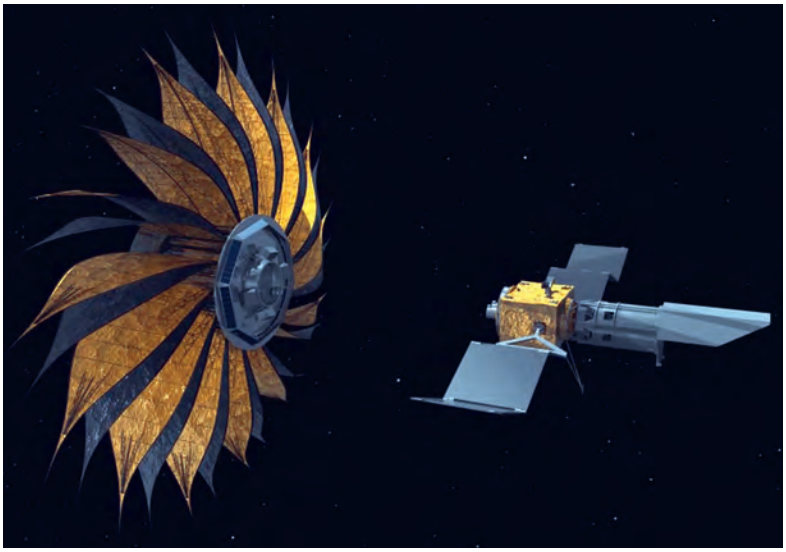
Accounting for uncertainty in engineering problems requires the quantification of observational noise, numerical discretization errors and other error sources in mathematical models. For simulations used for design, control, discovery and decision-making, quantifying these error sources using big data helps equip their solutions with a degree of confidence. The University of Texas at Austin has been developing **large-scale data-driven algorithms** to quantify the uncertainty in statistical inverse problems. Among those that are constructed and tested are derivative-enhanced Markov Chain Monte Carlo techniques, particle-based methods for Bayesian posteriors, randomization methods for big data in inverse problems, and triple-model — state, parameter and data — reduction methods. ★

Contributors: *Yongming Liu and Yi Ren*



Arizona State University

▼ **Engineers at Arizona State University** use advanced machine learning and probabilistic methods for characterization and reconstruction of the random microstructure of a titanium alloy. This methodology achieves the very high resolution at the voxel level and will eventually help the next-generation computational material design.



NASA

▲ **An artist's rendering** shows the proposed starshade concept flying in sync with a space telescope. The giant sunflower-like structure would be used to acquire images of Earth-like rocky planets around nearby stars.

Harnessing solar power via microwave

BY MARK LAKE, SERGIO PELLEGRINO AND JONATHAN SAUDER

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

This marked the third year since the **Spacecraft Structures Technical Committee** was formed from the former Gossamer Spacecraft Program Committee. The committee continues to actively recruit AIAA-related members interested in advancing the state of the art in this field.

Collecting solar power in space and transmitting it using microwaves has long appealed to the imagination of science fiction writers and aerospace visionaries. The **Space Solar Power Initiative** at CalTech, with support from Northrop Grumman Corp., is working toward turning this vision into reality by developing the critical technologies necessary to make space solar power economically feasible. The proposed system concept is a formation of ultralight deployable structural modules with high efficiency photovoltaics and microwave transmission antennas, supporting an array of foldable multifunctional tiles.

A gigawatt scale system would require hundreds of identical square modules flying in formation in a geosynchronous orbit, each with a size of 60 meters by 60 meters in the deployed configuration. Researchers in the Space Structures Laboratory at CalTech have developed a novel architecture for the modules, which uses high-strain composite strips that are tightly wrapped.

Smallsats and cubesats provide an opportunity to perform new science in a small package. While the miniaturization of electronics, propulsions systems, reaction wheels and many other components have enabled highly capable small satellites, one thing that cannot be miniaturized is antenna aperture. Consequently, there is a need for deployable, high-gain antennas that are useful for both telecom and radar applications. NASA's Jet Propulsion Laboratory at CalTech initiated a three-year research and development task to develop a 0.5 meter Ka-band (32-35 gigahertz) antenna that would produce an unprecedented 42 decibels relative to isotropic of gain, while stowing in 1.5 U form factor (10 by 10 by 17 centimeters) and weighing less than 3 kilograms. Additionally, with a height of just 16 cm and a mass of under 1.4 kg, the antenna surpasses its other design goals. The radar version of this antenna is being used to enable the **RainCube atmospheric profiling radar** in a cubesat mission, which is scheduled to launch in December 2017.

In January, NASA formed a **Starshade Readiness Working Group** to develop formal plans for validating the necessary technology for a starshade in time for a rendezvous with the Wide Field Infrared Survey Telescope, or WFIRST, in the mid-2020 time frame. NASA in April formally designated the starshade as a "technology development activity," and integrated disparate related projects at Princeton University, Northrop Grumman Aerospace Systems, and NASA JPL into JPL's "Starshade Technology Project." The goal is to mature all of the starshade's advanced deployable structures technologies before the end of the decade for consideration as an upgrade to the current WFIRST mission architecture during the next astrophysics decadal survey in 2020.

During 2016, JPL's **Starshade Technology team**, with support from Roccor LLC of Longmont, Colorado, completed fabrication and testing of 2 m and 5 m starshade engineering models to understand intricacies of the system's origami-like deployment kinematics, and evolve a more complete set of system engineering requirements to drive future technology and hardware development efforts.

Finally, the technical committee is preparing the "Handbook of Testing Large, Ultra-Lightweight Spacecraft." The handbook will provide both the theory and especially the practice of testing these unique spacecraft for project managers and technical specialists. Eleven chapters are under development by leading experts in the field. Expected publication by AIAA is in 2017. ★

Orion module undergoes acoustic testing

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.

Research and development proved fruitful in 2016 in the disciplines of structural dynamics as evidenced by the work of industry, government and academic members of the AIAA Structural Dynamics Technical Committee.

Vibroacoustic testing was performed at NASA Glenn Research Center, Cleveland, on the Orion Multi-Purpose Crew Vehicle's European Service Module Structural Test Article, or E-STA. The module provides Orion with propulsion, electric power, thermal control and fluid storage. The **E-STA Acoustic Test Campaign** occurred in the spring at the Reverberant Acoustic Test Facility at Glenn's Plum Brook Station. Participants included the European Space Agency, Airbus, Dutch Space, Lockheed Martin and NASA.

Ten acoustic tests were performed on the E-STA over a three-week period. The primary conclusions from the test were: The solar array wing was successfully mechanically test qualified; both ESA and Airbus along with NASA agreed that the E-STA test article was in a good structural health; and all organizations agreed that the E-STA test campaign was successful relative to the objectives. Next, the E-STA hardware was sine vibration tested at Plum Brook's Mechanical Vibration Facility and plans were made for the Direct Field Acoustic Test at Plum Brook in early 2017.

ATA Engineering performed ground vibration tests to support development of novel, **highly flexible sailplanes** to support flight testing and stability analysis. The Perlan Project is an attempt to fly a sailplane up to 90,000 feet using only the energy of "mountain waves." Perlan will be attempting this feat in its sailplane, the Perlan 2, before the year ends. With its 85-foot wingspan, the Perlan 2 is larger and more flexible than most gliders, introducing the potential for flutter. Perlan officials approached ATA to perform a predictive flutter analysis using a finite element model. Before the flutter analysis could begin, the model needed validating and this was accomplished through a ground vibration test of the airplane.

The test provided the data needed to correlate modal properties against the finite element model. Once satisfactory correlation was achieved, ATA performed the flutter analysis. The results will be used by Perlan to guide the flight testing program.

The University of Michigan's Aerospace Engineering Department received a five-year grant from the Air Force Office of Scientific Research for the topic "Avian Inspired Morphing." Its goals are to study **gliding birds** and extract methods for improving unmanned systems' performance via active materials. The first year's effort focused on trailing edge morphing and eliminating the vertical tail. Birds control yaw by shape-changing horizontal tail, which has been emulated with a macro fiber composite tail section capable of coupled bending and twisting. This is a multi-university effort led by Michigan that includes Stanford, UCLA, Texas A&M, the University of British Columbia and the Royal Veterinary College in London, with researchers spanning bird biology, materials engineering, controls, sensing and structural dynamics.

University of Maryland researchers performed a 3-D aeromechanical analysis of the **Tilt Rotor Aeroacoustic Model**, or TRAM, a one-fourth scale model of the V-22 proprotor. Next-generation rotorcraft analyses are envisioned to use integrated 3-D analysis, in which rotor structures are modeled using 3-D finite element analysis. Developed by the U.S. Army's Aeroflightdynamics Directorate, X3D is a 3-D rotor multibody computational structural dynamics analysis tool designed to be coupled with Helios, the Army's next-generation computational fluid dynamics framework.

In collaboration with the Aeroflightdynamics Directorate and NASA' s Ames Research Center in California, the University of Maryland has been working toward detailed structural modeling of TRAM and validating X3D predictions. Coupling X3D structural dynamics with Helios aerodynamics resulted in excellent correlation between predictions and experimentally measured dynamic airloads in the loads critical conversion corridor and revealed complex dynamic stress/strain patterns on the rotor blade and hub.

Based on the success of this pilot project — the first integrated 3-D analysis of a real rotor system — the University of Maryland received a five-year grant from the Army to develop new methods and algorithms toward exascale simulation of aeromechanics. ★

▼ **The Perlan Project is an attempt to fly a sailplane** up to 90,000 feet using only the energy of "mountain waves."

Perlan Project Inc.

Aerospace structures showed diverse advances

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.

Gulfstream Aerospace

▲ **Gulfstream Aerospace** said in June that it had completed ultimate load testing for its new Gulfstream G500.

The Air Force Institute of Technology in 2016 conducted experimental research to determine the optimum topology of hard-target penetrating warheads. By removing some of the warhead's exterior case mass and replacing it with an optimized current material interior support structure, a design is achievable that has comparable stiffness and increased lethality. The potential for designing warheads tailored to their intended targets was demonstrated, which are additively manufactured by operational military forces. Finite element methods, dimensional analysis, design of experiments, response surface methodology feasibility studies, and design of a vacuum lighter than air vehicle will be used.

Massachusetts Institute of Technology researchers have demonstrated improved composite properties via nanocomposites and hierarchical advanced composite nanoengineering. **New Archimedean scrolled fibers** of graphene and polymer were created. Large increases in in-plane strength derived from the reinforced interfaces have been realized.

The main applications of remotely piloted aircraft systems, or RPAS, are photo and video production, agriculture, maintenance services, security and law enforcement. Advantages of light (less than 25 kilograms) and very light (less than 4 kg) multicopter drones are low cost and high safety levels for activities performed in visual line of sight; whereas fixed-wing RPAS are mainly used for 10-100 kilometer ranges and greater than one-hour endurances. A promising aerodynamic concept is the **high-efficiency PrandtlPlane configuration** developed by SkyBox Engineering of Italy and is not limited to drones.

NASA's **Marshall Space Flight Center** in Alabama completed the first series of high-tech composite tests. A composite cylindrical barrel was tested to failure under compressive loads of 900,000 pounds to achieve lighter, stronger primary future structures. Forces were increasingly applied to the composite barrel top to evaluate structural integrity. Predicted failure loads were within 1 percent of actual ones. Tests were performed on the 8-foot-diameter, 8.4-foot-tall graphite-epoxy, honeycomb-core sandwich composite barrel outfitted with 300 individual sensors and approximately 16,000 fiber optic sensors to evaluate the barrel's structural integrity.

Tests have been conducted at NASA's Langley Research Center in Virginia on stitched, low-weight, high-strength Pultruded Rod Stitched Efficient Unitized Structure, or PRSEUS, composites developed by Boeing's Blended Body Group at Huntington Beach, California. The multibay box represents a center section wing part and is made of a low-weight, damage-tolerant stitched composite. The PRSEUS concept significantly improves structural efficiency and lowers manufacturing costs of composite primary structures for large transport aircraft.

Researchers at the AIMS Center at Arizona State University are investigating the multi-axial fatigue behavior of aerospace grade alloys under diverse loading conditions. The goal is to understand the effects of complex loading on microstructural deformation, crack growth behavior and fatigue life. Severely retarded crack growth was observed immediately after overload occurrences and the retardation was found to be directly proportional to the magnitude of the overload. Overloads of higher magnitudes cause increased crack closure due to larger plastic zones around crack tips. The research is supported by technical data analysis.

Gulfstream Aerospace has completed load testing for its G500 aircraft for FAA and European Aviation Safety Agency certifications. Bending and torsion tests focused on the fuselage, wing, vertical and horizontal stabilizers and control surfaces and contained more than 6,000 channels of instrumentation to gain real-time insight into structural behavior. Additional tests will be conducted to determine structural destruction points.

NASA's Johnson Space Center and Bigelow Aerospace engineers worked to launch, attach and deploy the first human-rated, inflatable spacecraft module. The Bigelow Expandable Activities Module, or BEAM, was launched and expanded for a two-year durability. Crews will enter the module periodically to retrieve recorded data. The module will further the understanding of material susceptibility to creep in both the BEAM bladder and the restraint layer. ★

Boeing

▲**The U.S. Air Force** completed its final live-fire test for Boeing's new KC-46 Fuel Tanker.

Lessening blast effects in closed spaces

BY AMEER G. MIKHAIL, GREGORY J. CZARNECKI AND MARK E. ROBESON

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

The U.S. Army is developing a durable lightweight composite sandwich core structure to mitigate the effects of blasts internal to an enclosed helicopter fuselage. Two full-scale subcomponent test articles were subjected to blast and ballistic fragmentation from a high-explosive incendiary round. Residual strength testing of the damaged components was then conducted to demonstrate that sufficient strength remained to carry loads corresponding to level flight. The components did carry these loads, as well as increased maneuvering loading. Simulation models previously improved with building block test data were critical in designing this structure to tolerate damage while providing adequate residual strength.

Wright-Patterson Air Force Base in Ohio completed the 10th and final **live-fire test and evaluation** series for Boeing's KC-46 Fuel Tanker. Included was a long-term burn test (over 30 minutes) with airflow to assess cascading structural damage. The results were transitioned into Boeing's Systems Integration Laboratory for pilot-in-the-loop developments for KC-46 training, tactics, operations and procedures.

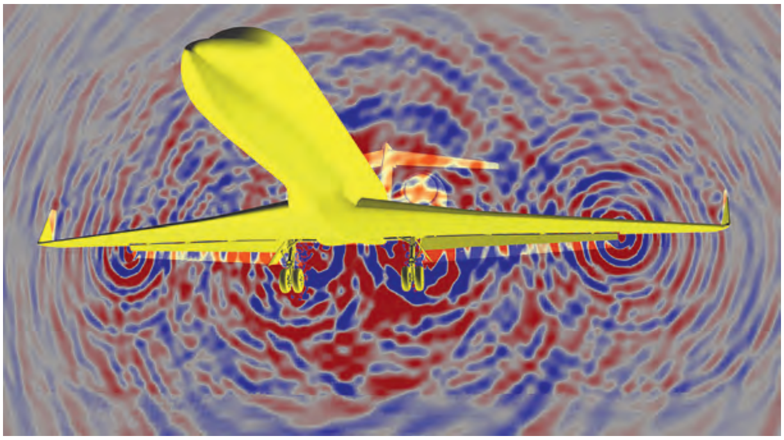
Air Force officials at Wright-Patterson are collaborating with the Army and Navy to assess **thermo-mechanical failure effects** on aircraft composite materials. The goals are to determine composite material loss of strength from fire and lasers, generate time-dependent damage data, and quantify the fire-resistance of selected thermal barriers. The results will be applied to aircraft vulnerability assessments and to protective system designs.

Wright-Patterson, along with the other military branches and industry organizations, is also assessing **unmanned air vehicle vulnerabilities** to high energy lasers. Tests include quantifying penetration times and thermal effects, investigating the potential for fuel fires, examining power and signal loss in wire bundles, assessing control box and actuator dysfunctions, and assessing hardening concepts for delays in damage onset of effects. Data obtained will be used to support laser effects modeling.

The Air Force base also completed an F-35B fuel tank ullage test that enabled the aircraft's program office to meet its critical initial operational capability milestone. The test addressed critical fuel tank vulnerability issues affecting flight operations. The results enabled the **F-35 program** to prevent suspension of a critical halt of F-35B fleetwide low-rate initial production regarding fuel tank modifications, which led to cost savings. Test data allowed lifting a 10-nautical mile Lightning flight restriction that resulted in direct benefit to training, operation, tactics and procedures.

For pilot survivability in the three versions of the new F-35 fighter, Lockheed Martin has chosen the British company Martin-Baker over a rival competitor, United Technologies Aerospace System, to provide an upgraded version of its current US16E pilot ejection seat. Three nitrogen-filled bags around the pilot's head are instantly inflated to protect the head and prevent neck whiplash, among other improvements.

For space systems, the heat shield of the **Orion re-entry module** and capsule for the mission to Mars is being redesigned to withstand 4,500 degrees Fahrenheit instead of 4,000. NASA contractor Lockheed Martin and its partner Textron are reconfiguring the shield's Avcoat epoxy resin material in a different design to avoid a shield cracking problem during re-entry into Earth atmosphere. In addition, to protect the crew against solar radiation near Mars, the contractor is collaborating with StemRad of Israel in developing a crew vest to be worn over the space suit inside the Orion when radiation is above an acceptable level, and also in spacewalks if outside repairs to the Orion are needed. ★



NASA Langley Research Center

Collaborating for quiet flight

BY DENNIS K. MCLAUGHLIN AND STEVEN A.E. MILLER

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.

▲ **Shown are the contours of acoustic pressure** that are radiated from a Gulfstream aircraft landing with wing flaps deflected 39 degrees and the main landing gear deployed.

The understanding and reduction of radiated noise by aerospace flight vehicles is central to reducing developmental and operations costs within the military and commercial sectors in air and space. The aeroacoustics research and development community made substantial efforts this year in pursuit of these goals.

The noise from military aircraft jet exhaust is an annoyance to the community and is harmful to military personal. Computational research groups at the Naval Research Laboratory of Washington, D.C., Purdue University and Craft Tech of Pennsylvania performed large eddy simulations with more complicated nozzle geometries and jet conditions closer to those of realistic jet engine exhausts. Additional computations involved the use of the immersed boundary method. Measurements of the aero-acoustic performance of multistream rectangular nozzles are underway at the universities of Texas and Mississippi to accompany the computational predictions. Similar jet exhaust experiments are being pursued at NASA Glenn Research Center in Ohio as part of a feasibility study for future supersonic airliners capable of meeting acceptable airport noise and sonic boom regulations.

Airframe noise simulations and predictions were conducted by NASA's Langley Research Center in Virginia to evaluate several full-scale flap and landing gear noise reduction technologies. Far-field noise data from a Gulfstream aircraft flight test were used to validate the computed solutions. UTC Aerospace Systems' Aerostructures unit has started its ecoIPS program, which integrates a suite of nacelle system innovations bringing together the engine, nacelle system and pylon into a complete underwing package. The innovative technologies include a short fan duct with integrated thrust reverser to reduce drag as well as improved acoustic treatment for community noise reduction. The demonstration unit will be tested on a **Pratt & Whitney PW1000G Geared Turbofan engine** in 2019 under the FAA's Continuous Lower Energy, Emissions, and Noise program.

NASA and Boeing are using large-scale Detached-Eddy Simulations to provide space-time coherence of surface pressures for structural-vibration predictions for NASA's Space Launch System vehicle, SLS. The fluctuating forces created during ascent through the atmosphere produce an important design condition for launch vehicles. NASA's Ames Research Center in California conducted a **Buffet Verification Test** in the 11-foot Unitary Plan Wind Tunnel in November 2015 using a generic model of a launch vehicle, fast response pressure sensitive paint and a large number of dynamic pressure sensors. The data collected from the test are now processed and used for computational validations. The University of Texas in Austin, in collaboration with NASA's Marshall Space Flight Center in Alabama, completed a series of tests in August to quantify the acoustic loads that develop at the SLS launch pad. The measurements used four nozzles and focused on vibracoustic loads during nozzle startup and the effects of compliant nozzle walls on aero-elastic behavior. The findings are being used to develop a refined model of the launch pad environment that is expected to occur during startup of the SLS vehicle.

A consortium in Europe is performing comprehensive **Research on Core Noise Reduction** (the RECORD project). Leading engine manufacturers, research establishments and universities have joined forces to develop, validate and exploit methods for combustion noise prediction and control. An integrated approach is underway to understand noise sources from the combustor and their interaction with the turbine. Various numerical models from large eddy simulations to low-order physical models are applied to the reacting flow in a combustion chamber. The assessment of the achievements of RECORD is made by comparing these combustion noise calculations with existing real engine data. ★

Research stays strong for aero measurements

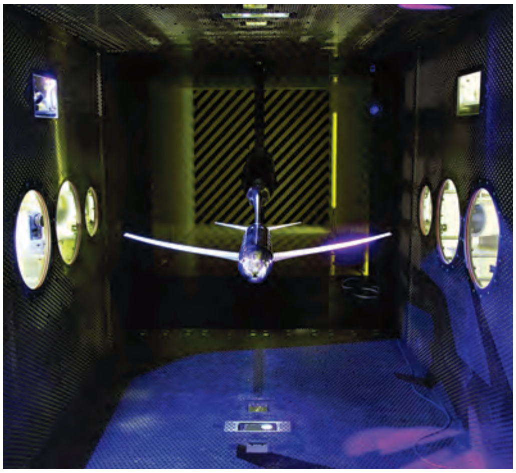
BY DAVID PLEMMONS AND TOM JENKINS

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

The wind tunnel team at Sandia National Labs continues this year to advance its time-resolved **particle image velocimetry**, or PIV, capability using a pulse-burst laser. In its most recent configuration, measurements have been achieved at an astounding 400 kilohertz though restricted to a small field of view — which therefore has been dubbed "postage-stamp PIV." More than 4,000 sequential vector fields can be acquired. This unprecedented framing rate is well-suited to measuring turbulent velocity spectra in high-speed flows and is being used to improve the physical models underlying aerodynamic simulations.

The new HORIZON research group — High-speed Original Research and Innovation Zone — at The University of Tennessee Space Institute has been exploring the use of high-speed Schlieren imaging as an alternative to conventional dynamic surface pressure measurements in the characterization of unsteady **transitional shock wave and boundary layer interactions**, or XSWBLI. In one of the first studies of its type, the group is post-processing large data sets of images to build statistical models for the interaction dynamics of XSWBLI in a manner similar to that developed for turbulent interactions using dynamic pressure transducers in the past.

North Carolina State University has developed a laser-based combustion diagnostic technique to measure gas-phase temperature and pressure that does not require any knowledge of the local composition of gases. This is a new method that makes use of spectral line broadening of a seeded or naturally present absorbing species in the flow field. The university's preliminary evaluation of the method has been demonstrated in an atmospheric CH_4/N_2 laminar nonpremixed flame. Uncertainties of about 12 percent have been demonstrated for both temperature and pressure. These results demonstrate a strong potential for developing this method to a robust technique for realistic flow environments.



JAXA

A scaled NASA Common Research Model is installed in the Japan Aerospace Exploration Agency's 2-meter by 2-meter transonic wind tunnel for tests that include unsteady pressure sensitive paint.

Diagnostics that can resolve the 3-D structures of highly turbulent flames have long been desired. Researchers at Virginia Tech and the Air Force Research Laboratory recently demonstrated 3-D combustion measurements based on a technique named VLIF, or **volumetric laser induced fluorescence**. The 3-D VLIF measurement technique has been validated by comparing cross sections of VLIF images to coincident planar LIF images acquired with an independent camera. The close overlap observed demonstrates the fidelity and accuracy of the VLIF technique to provide instantaneous 3-D measurements of turbulent flames. The VLIF technique will be used in future tests to resolve 3-D structures of highly turbulent flames and provide key combustion properties such as flame front location, surface area, volume and curvature.

Researchers at the Air Force Research Laboratory, Aerospace Systems Directorate and the University of Tennessee demonstrated rotational temperature measurements through ceramic materials in a cylindrical flow reactor and toroidal well-stirred reactor by utilizing see-through-wall coherent microwave scattering from **Resonance Enhanced Multiphoton Ionization** of molecular oxygen.

Gas temperatures inside the reactors have been measured with an uncertainty of 3 percent. For gas temperatures of 800 degrees Fahrenheit, or 700 Kelvins, this amounts to an accuracy of approximately plus or minus 20 Kelvins. This technique shows great potential for noninvasive, high-fidelity quantification of spatially localized temperature in combustion kinetic experiments and confined combustors constructed of advanced ceramic materials in which limited or nonexisting optical access hinders usage of conventional optical diagnostic techniques to quantify thermal nonuniformity.

The Japan Aerospace Exploration Agency and Tohoku University in Sendai, Japan, have conducted unsteady **pressure-sensitive paint**, or PSP, measurement tests to investigate the transonic buffet on the 80 percent scaled NASA Common Research Model. The main wing of the model was painted with fast-response PSP having negligible surface roughness effects and illuminated by a high-power violet LED. Unsteady PSP images were captured at the rate of 5 kHz. The time-series pressure maps clearly showed the dynamic behavior of the transonic buffet on the main wing. ★

Understanding aerodynamics for small, large craft

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.

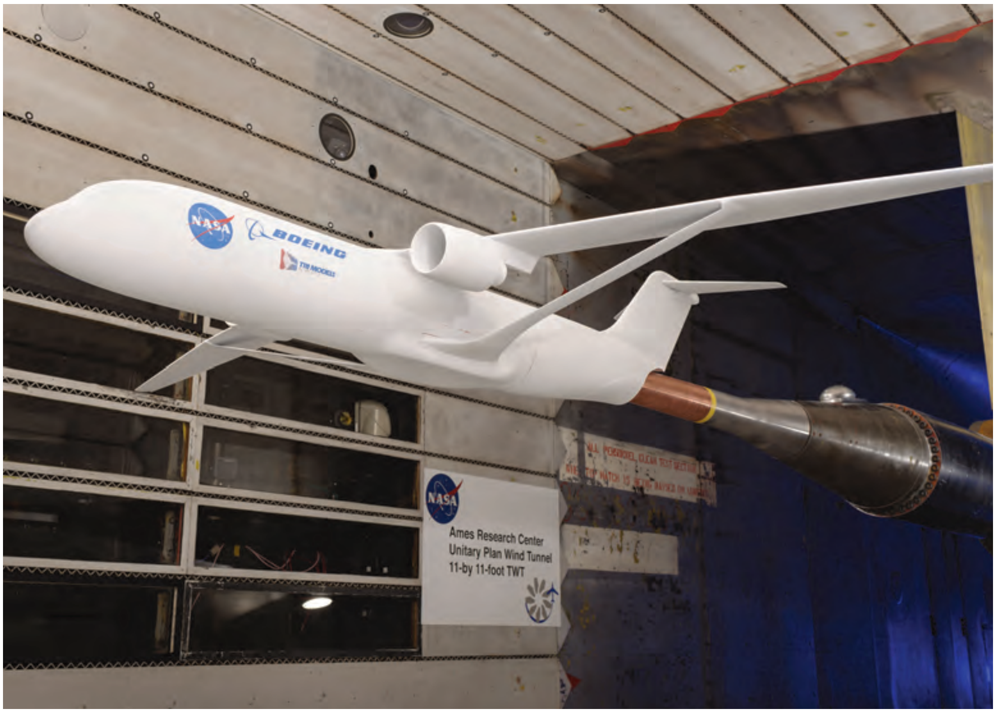
NASA's Advanced Air Transport Technology Project and Boeing tested a 4.5-percent scale model of a **Transonic Truss Braced Wing**, TTBW, aircraft concept in the 11-Foot Transonic Wind Tunnel at NASA's Ames Research Center in California. Force, moment and surface pressure data were obtained with the use of multiple optical measurement techniques. Model component build-up data and drag-rise data were obtained on both baseline strut and alternate strut configurations.

Control surface deflections were also investigated to support the assessment of stability and control characteristics. The TTBW configuration is expected to produce at least a 50 percent reduction in fuel burn and carbon emissions compared to current transport aircraft, and a 4 to 8 percent reduction compared to an equivalent conventional advanced technology configuration. Initial test analysis shows the TTBW as a promising technology for future energy efficient transports.

The Advanced Vertical Flight Laboratory at Texas A&M University designed, built and flight-tested a 62-gram hummingbird-inspired flapping wing **micro air vehicle**, or MAV, with hovering capability. The robotic MAV was developed as a part of DARPA's Nano Hummingbird initiative. The MAV was developed specifically for the purpose of scientifically investigating the flight dynamics, aerodynamics, and control of an actual flying vehicle utilizing flapping-based aerial locomotion. Additionally, Texas A&M tested the world's smallest cyclocopter. A cyclocopter, unlike traditional helicopters, deploys a rotor with horizontal axis of rotation, allowing complete 360 degree thrust vectoring capabilities.

The Naval Surface Warfare Center's Carderock Division investigated the aerodynamic hover performance of a series of generic **Fan-in-Wing**, or FIW, configurations in their 8-foot by 10-foot Subsonic Wind Tunnel. The model was designed to allow the fan performance and overall FIW system performance to be measured independently. Researchers at the center are now preparing to test the FIW configurations in forward flight.

The Defense Department's CREATE program, short for **Computational Research and Engineering Acquisition Tools and Environments** program continued developing and deploying scalable, multidisciplinary, physics-based computational engineering products for the design and analysis of ships, air vehicles and RF antennas. CREATE is part of the **High Performance Computing Modernization Program**. The Air Vehicles program, HPCMP CREATE-AV, released three products in 2016: the fixed-wing analysis tool Kestrel7.0, the rotorcraft analysis tool Helios7.0, and the conceptual-design tool DaVinci4.0. Kestrel7.0 introduces full-engine integrated aircraft simulation capability and Helios7.0 introduces integration of Kestrel core solver kCFD and NASA's FUN3D, engine models and automated strand-based body mesh/solution for solving rotorcraft simulation problems. DaVinci4.0 enables rapid generation of parametric aircraft designs, including the ability to generate computer-aided-design outer-mold-lines and basic internal structures. ★



Boeing

◀ **NASA's Advanced Air Transport Technology Project** and Boeing tested a 4.5-percent scale model of a transonic truss braced wing aircraft concept in the NASA Ames 11-foot Transonic Wind Tunnel.

SpaceX

▲ **In April, SpaceX for the first time landed** the first stage of the Falcon 9 on a drone ship.

Launch vehicles get commercial push

BY RYAN S. PARK

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

This was an exciting year for astrodynamics, with an emphasis on commercial space industry that pushed the envelope on launch vehicle and space business capabilities.

Followed by a successful recovery of a reusable **Falcon 9** booster on a landing pad on solid ground in December 2015, SpaceX accomplished an even more challenging success. On April 8, the company launched the two-stage Falcon 9 and delivered a robotic Dragon cargo vehicle carrying crew supplies to the International Space Station for NASA. After separation, the first stage of the Falcon 9 landed back onto a SpaceX drone ship off the Florida coast, marking a huge step toward development of a reusable launch vehicle that may be a paradigm shift for the astrodynamics community.

In April, Rep. Jim Bridenstine, R-Oklahoma, introduced the **American Space Renaissance Act**, which is meant to synergize and reform space enterprises across the United States and ensure U.S. leadership and success across the national space enterprise. The bill motivates a shift of space situational awareness from being a government-led activity to a civil or commercial solution for that function as well as space traffic management.

In August, NASA approved the **Asteroid Redirect Mission**, ARM, to proceed to the next design phase with $1.4 billion in funding. ARM is a two-step mission that will send a robotic spacecraft to bring back a boulder from a near-Earth asteroid, will return it to cislunar orbit and then send astronauts to visit and study the captured object.

Beyond cislunar space, NASA's **Juno** spacecraft rendezvoused with Jupiter in July and set a record as the most distant solar-powered spacecraft ever flown. Juno will be in a 14-day polar orbit around Jupiter with its perijove inside Jupiter's radiation belt, which was carefully designed to be in view from Deep Space Network antenna in Goldstone, California, during perijove passages. Juno will continue to study the structure of Jupiter's interior and atmosphere over its 18-month primary science phase.

In June, NASA approved the plutonium-powered New Horizons spacecraft to fly by the Kuiper Belt Object known as **2014 MU69** in January 2019. This will be the first visit to a Kuiper Belt Object, and to achieve this the New Horizons spacecraft had to conduct a targeting maneuver farther from Earth than any other spacecraft. In late June, Dawn surpassed all of the objectives of its primary mission at dwarf planet Ceres, despite two failed reaction wheels and a very limited supply of hydrazine available for attitude control. The Dawn team received the prestigious 2015 Robert J. Collier Trophy in recognition of the overall success in exploring Vesta and Ceres and the innovative use of ion propulsion.

Europe's **Laser Interferometer Space Antenna** (LISA) **Pathfinder** spacecraft, formerly called Small Missions for Advanced Research in Technology-2, reached the Sun-Earth L1 Lagrange point in January and demonstrated the ability to detect gravitational waves. While several spacecraft have incorporated low-energy orbits in their mission designs, LISA Pathfinder is the first mission to demonstrate low-energy, low-disturbance formation flying between two test masses, technology that enables detection of gravitational waves in space. ★

Atmospheric vehicles tilt toward 'going green'

BY JARED GRAUER AND CHRISTOPHER KARLGAARD

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

Many advances took place this year in technologies for atmospheric vehicles. There was a worldwide trend toward improving green aircraft technologies that aim to reduce noise and emissions, increase fuel efficiency and aerodynamic performance, and increase operational safety. From the perspective of atmospheric flight mechanics, meeting these goals presents new and exciting problems in aerodynamic modeling, aeroelasticity, flight controls, handling qualities and other topics.

In February, President Obama released a federal budget request that included a 10-year plan called **New Aviation Horizons**. The plan calls for a variety of advanced aircraft configurations to be built and flown as X-planes to mature and demonstrate key technological advances toward these goals.

One configuration, the **X-57 "Maxwell,"** was revealed in June by NASA Administrator Charles Bolden at the AIAA 2016 Aviation Forum in Washington, D.C. The X-57 is a modified Tecnam P2006T aircraft, intended to reduce fuel burn, emissions and noise through an array of 14 propellers driven by electric motors. This demonstrator follows other recent NASA pursuits in distributed propulsion, including the hybrid-electric integrated systems test bed and the GL-10 aircraft.

Another configuration is the **Blended Wing Body**, a joint effort by Boeing and NASA to improve structural, aerodynamic and operational efficiencies. After previous testing at NASA Langley Research Center, Virginia, and NASA Ames Research Center, California, the aircraft test model returned to the Langley 14-foot by 22-foot subsonic wind tunnel in September for additional testing to examine conditions around the engines and to apply flow visualization techniques.

A third set of configurations utilize different wing bracing concepts to make the wings smaller and lighter, which is expected to result in 50 percent lower fuel burn and carbon emission. The truss-braced wing model was tested at the NASA Ames Unitary Plan Wind Tunnel outside San Francisco.

Aurora Flight Sciences

▲ **Testing on a 1 to 5 subscale demonstrator** of the LightningStrike vertical takeoff and landing experimental plane by Aurora Flight Sciences took place in March.

DLR, the German Aerospace Center, conducted flight tests with the **HALO aircraft** — high altitude, long operation — under the iLOADS mission, between March and April in Oberpfaffenhofen. The Gulfstream G550 airplane was instrumented with many accelerometers and strain gauges and was flown through atmospheric turbulence to verify numerical predictions of aircraft loads and to review aeroelastic stability.

Other interesting flights this year were performed by long-range, high-endurance and solar-powered aircraft. In July, the Swiss-built **Solar Impulse 2** aircraft finished its multistop circumnavigation of the Earth. This 16-month journey covered 42,000 kilometers using only solar power. In March, the University of Maryland achieved the first successful flight of a manned solar-powered helicopter with Solar Gamera, a reincarnation of the Gamera human-powered helicopter.

In June, Facebook had its first successful flight of the **Aquila** solar-powered aircraft in Yuma, Arizona. The airplane weighs 900 pounds, has a 141-foot wingspan, and is intended to provide internet access to people in low-density areas. Aurora Flight Sciences in Manassas, Virginia, was awarded a phase two contract by DARPA to build and demonstrate the LightningStrike VTOL concept, which can take off vertically and then transition into a forward flight mode under distributed propulsion. A 1/5 scale demonstrator was flown in March.

Technologies related to atmospheric flight mechanics are often flown on small unmanned aircraft systems. In August, **FAA Part 107 Rule** became effective, which offers safety regulations for aircraft under 55 pounds. This rule came after operators were required to register their aircraft with the FAA by February, and ahead of additional rules to expand the range of operations. ★

Characterizing engine ice, solving a GPS mystery

BY ASHLIE FLEGEL, DALE FERGUSON AND JUSTIN LIKAR

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

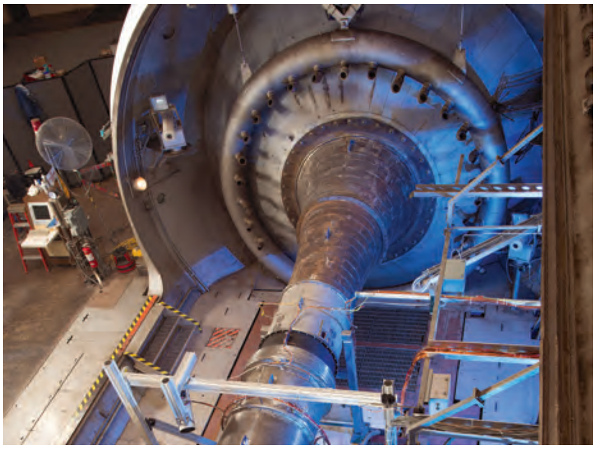
NASA's Glenn Research Center in Ohio this year completed two tests in its Propulsion Systems Laboratory (PSL) 3 facility focused on increasing the understanding of **engine ice-crystal icing**. This phenomena can lead to power-loss events and can occur when jet engines ingest a large amount of ice crystals during flight in clouds.

A full-scale engine ice-crystal icing test was completed in November 2015. This test utilized a heavily instrumented engine model, specifically an unmodified **ALF502 engine** that had previously experienced an uncommented loss of thrust event called a rollback. Engines of this model have been modified to eliminate engine icing issues. Advanced instrumentation and internal cameras characterized the cloud entering the engine, detected and characterized ice accretion, and visualized the ice accretion in the region of interest. During this test, PSL replicated key in-flight icing event points including a rollback and nonrollback event. Icing videos inside a full-scale engine during ice-crystal icing were acquired for the first time. This study has enabled advanced instrumentation development, expanded the capabilities of PSL, and provided a dataset for developing and validating in-house icing prediction and risk mitigation codes.

In addition, NASA Glenn conducted a test investigating the fundamentals of ice-crystal icing utilizing a static airfoil. A mixed-phase cloud, which simulates the conditions inside the compressor region of the engine, impinged on the airfoil placed at the exit of the PSL contraction operating as a free jet. Ice accretions were generated on the airfoil and recorded on video. This data will help NASA develop ice-crystal accretion modeling tools that ultimately seek to reduce icing issues for future engine designs.

Turning to the space environment, the U.S. Air Force Research Laboratory (AFRL) in New Mexico in April reported novel results in the study of flashover events and electrostatic-discharge contamination damage to solar arrays. The results were presented at the 14th **Spacecraft Charging Technology Conference** in the Netherlands. Evidence is mounting that excess power loss observed on GPS satellites is due to contamination from arcing on the solar arrays. Flight contamination monitors confirm that solar cell coverglass contamination is responsible for the degradation. **Radio-frequency detectors** developed by Los Alamos National Laboratory for GPS satellites experience short-timescale events that have not been dispersed by the ionosphere and so must come from the satellites themselves. Rates of these signals are highly correlated with the three-hour fluences of surface charging electrons at greater than 10 kiloelectron volts as determined with the AE9/AP9/SPM empirical climatology model developed by AFRL, the Aerospace Corporation and the National Reconnaissance Office. A ground-based surveillance campaign in 2015 reported preliminary detection of signals that may be radio emissions from the GPS arcs.

The detected emissions are consistently seen in on-source observations but do not show up in off-source observations even with the same receivers 10 minutes apart. Ground tests in AFRL space plasma chambers show that GPS-like arrays arc at thresholds consistent with the voltages that may develop on GPS satellite arrays in their orbital environment and, after thousands of arcs, current-voltage, or I-V, curves show degradation consistent with the GPS on-orbit power losses. Rates of the events sensed by the Los Alamos detectors, although rapid, are also consistent with the amounts of contamination necessary to produce the observed power degradation. The unexpectedly high rates of arcing may be evidence for the effectiveness of power-supply filtering employed on modern satellites. If the detection is confirmed, arc-mitigation techniques may be used on succeeding GPS satellites. Elimination of the excess power degradation would permit future GPS satellites to be launched with 20 percent smaller solar arrays or with a 25 percent increase in end-of-life power. ★

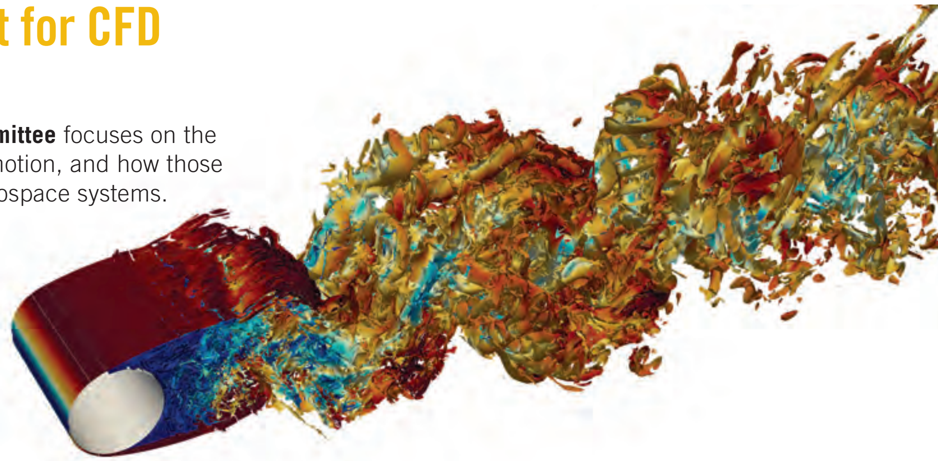

NASA

NASA Glenn Research Center completed tests focused on increasing the understanding of engine ice-crystal icing utilizing its Propulsion Systems Laboratory 3 facility in Ohio.

A new challenge set for CFD

BY TIM EYMANN AND QIQI WANG

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.



Koen Hillewaert/Cenaero Research Center

This computational fluid dynamics simulation of air flowing over a cylinder serves as a model for visualizing the more advanced flows around high-lift devices such as the flaps and slats on aircraft.

Researchers worldwide have been tackling the challenges faced when using **computational fluid dynamics** to simulate complex flows that occur during aircraft take off, landing and maneuvers. High-order CFD methods are well suited for these types of problems because they provide a more accurate representation of the fluid compared to low-order methods used in the majority of production CFD codes.

Participants at the 4th **International Workshop on High-Order CFD Methods** demonstrated that high-order methods can be effectively applied to complex, time-accurate and steady-state cases of interest to industry. For example, researchers showed that high-order schemes are more computationally efficient relative to second-order schemes for transitional flow over low-pressure turbine blades. Meshing also emerged as an important consideration with presenters showing the advantages of adaptive schemes and highlighting the importance and difficulties of generating curved meshes, particularly for three-dimensional problems requiring anisotropy. NASA has set a 2017 goal to improve the numerical methods used to simulate a wide range of physics by identifying the most promising techniques and further developing them to reduce their predictive error by 40 percent.

To meet this challenge, NASA worked closely this year with the **AIAA Turbulence Modeling Benchmark Working Group** to identify a set of test cases that are simple enough to be useful but still possess the relevant flow physics. CFD developers will use these cases to tune and refine their codes, increasing the community's ability to accurately predict this class of problems.

Researchers at Missouri University of Science and Technology (Missouri S&T) and NASA's Langley Research Center in Virginia developed a database of direct numerical simulations of broadband acoustic radiation from turbulent boundary layers ranging from Mach 2.5 to Mach 14. Such simulations will advance the understanding of flow in conventional high-speed wind tunnels. The simulations and database will improve how wind tunnel data are scaled up to match the actual flight conditions and will eventually enable better modeling of the laminar/turbulent transition process.

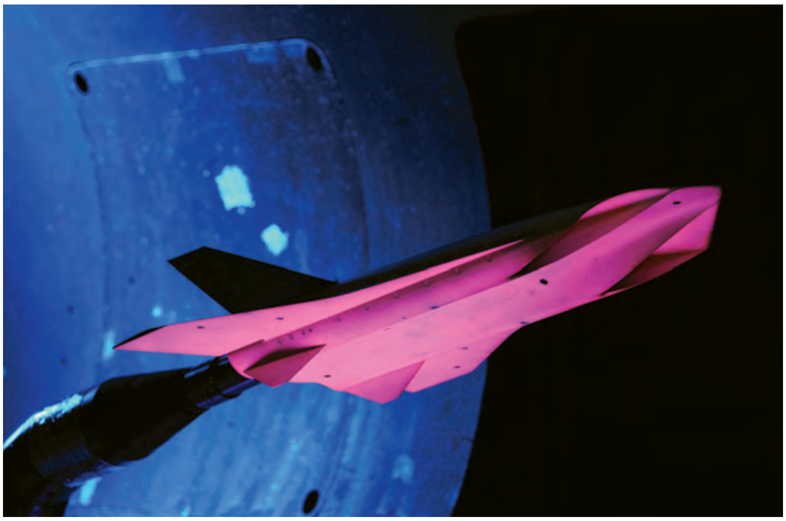
Fluids researchers are also investigating landing high-mass payloads on Mars. The large mass of these vehicles, combined with a thinner atmosphere, means that conventional technology such as rigid aeroshells and parachutes aren't as effective at slowing a craft for landing as they would be on Earth. One way around the problem is to use inflatable devices that significantly increase the drag on the vehicle. The devices are designed using complex simulations of the spacecraft re-entry. Engineers from NASA and Missouri S&T collaborated to implement efficient approaches to characterize the sensitivity and the level of uncertainty in these entry simulations due to variations in physical phenomenon and how they are modeled. The ultimate goal of the work is to validate and improve the physical models that contribute to the design of reliable thermal protection systems for **inflatable aerodynamic decelerators**.

Speakers at the **"Future of Fluids"** special session of the 2016 AIAA Aviation Forum discussed some of the key areas of fluid dynamics research and reached the following four conclusions: fluid dynamics will play an increasingly important role in the future of environmentally responsible aviation; turbulence research needs to address more complex situations such as unsteady flows; exascale computing power could be used to build data-driven, reduced-order flow models that include system nonlinearity; and a fundamental understanding of fluid dynamics in energy and propulsion is necessary to improve safety and reliability in domestic replacement for Russian rocket engines. ★

Ground tests: An eye to modernizing

BY RYAN KEW

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



U.S. Air Force

▲ **As part of the program** known as Hypersonic International Flight Experimentation, an aerodynamic and aerothermal test and analysis of a hypersonic cruise vehicle was completed in Hypervelocity Wind Tunnel 9 at the Arnold Engineering Development Complex in Maryland.

Ground testing in 2016 focused on modernizing the U.S. facility infrastructure and the application of advanced test techniques in the subsonic through hypersonic flight regimes. Some of that testing included:

- **Upgrades to the National Transonic Facility at NASA Langley Research Center, Virginia —** These aimed to improve both data accuracy and repeatability. Increased temperature stability and force measurement accuracy of their semispan balance made this possible. Tests conducted with Lockheed Martin Skunk Works' hybrid wing body were used to build confidence and validate existing computational fluid dynamics models of drag.
- **Lockheed Martin's Hybrid Wing-Body Future Airlifter —** At the 11-foot transonic tunnel at NASA Ames Research Center, California, an investigation under contract with Boeing was performed on a 4.5 percent scale transonic truss braced wing model. A stepped model component build-up procedure collected a battery of data including force-and-moment, surface pressure, model deformation, pressure sensitive paint and surface oil flow visualization in an effort to assess drag rise data and stability and control characteristics.

Hypersonics saw a collaboration between the Arnold Engineering Development Complex in Tennessee and the U.S. Air Force Research Laboratory in Ohio as part of a **Hypersonic International Flight Experimentation**, or HIFEX, research program. The project is designed to advance the maturing technologies for a next-generation hypersonic cruise vehicle. Future collaborations on an axi-symmetric scramjet flow path and specific canonical geometries aimed at providing workforce revitalization are in the works as important follow-on activities in the Hypervelocity Wind Tunnel 9 facility in Maryland.

The High Enthalpy Shock Tunnel at the Japan Aerospace Exploration Agency conducted a test with a re-entry HYFLEX, or **Hypersonic Flight Experiment** model. Using a new preflight technique that included 16 piezoelectric-charge type accelerometers, eight pressure transducers and three onboard data recorders captured critical data to evaluate the effects of high temperature real gas effects on pitching moment and related body flap efficiency.

The **Holloman High Speed Test Track** in New Mexico operated by the U.S. Air Force's 846th Test Squadron is the longest and most precisely aligned track in the world. Designed in 1964, that track has been used to simulate hypersonic flight and aerothermal testing with 240 hypersonic missions conducted to date. The test that took place on March 4 sent the sled accelerating at 633 mph, shattering the previous record of 513 mph. Efforts to conduct Mach 10 tests in the future are currently underway.

In space exploration, NASA Glenn Research Center's Plum Brook Station near Cleveland contains the largest space environment simulation facility in the U.S. and is preparing to begin testing every element of the Orion spacecraft's power and life support systems. A full-sized European Service Module will be used by engineers at the facility in a suite of tests. The first test will verify the mechanical movement of the solar array followed by pressure and vibration bombardment of the **European Service Model**'s separate elements and then as the system as a whole in the acoustic test chamber. Finally, the module will move into the mechanical vibration facility's table to simulate the vibration experiences during launch. The tests are critical to verify the flight readiness and the structural integrity of the Orion module.

The Arnold Engineering Development Complex/National Full-Scale Aerodynamic Complex facility in Moffett Field, California, conducted complete system tests to obtain flight qualification of two separate parachute systems. The first test included two mortar deployments of the European Space Agency's **Exomars parachute**. The second included 16 mortar deployments of parachutes for the NASA Joint Propulsion Laboratory's InSIGHT stationary lander program. Both test campaigns were successful in obtaining their qualifications. ★

Contributor: *Dan Lewis*

FAA

Big strides in air control

BY LESLEY WEITZ, UDAY SHANKAR AND JOHN REED

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

Ground-based Interval Management Spacing uses modern technology to improve the sequencing and spacing of aircraft arriving at airports such as Phoenix during peak traffic hours.

Throughout 2016, the FAA continued its deployment of a new air-traffic-control ground automation capability, called **Ground-based Interval Management Spacing**, to assist controllers in sequencing and scheduling aircraft into terminal radar control areas during busy traffic periods. This capability leverages automation functions that predict aircraft trajectories to merge points in the airspace and schedules times to cross those points. Once a flight's schedule at downstream points is determined, the air traffic controller is presented with a speed advisory, calculated using a model of the aircraft's trajectory and forecast winds along the flight path, to meet the schedule. This system is expected to reduce the use of costly holding patterns or route extensions that may occur without the assistance of automation. This new system has been deployed for aircraft flows into the Phoenix, Denver and Seattle airports, and the FAA plans to continue deployment at other airports.

RTCA Special Committee-228 is completing work on the **Minimum Operational Performance Standards for Detect and Avoid**, or DAA, equipment on remotely-piloted aircraft. This initial standard focuses on civil unmanned aircraft systems that operate in Class D, E and G airspace under Instrument Flight Rules. DAA systems serve as a replacement for the "see and avoid" requirement for piloted aircraft. The new standard includes a definition for "well clear," specifying the threshold between sufficient separation between the UAS and another aircraft and when the UAS pilot must take action to avoid a loss of separation. To support this work, researchers have conducted several studies, spanning the past few years, of pilot displays and UAS maneuver options to ensure that aircraft remain "well clear" of other aircraft.

Turning to space, the year has seen major strides in the launch vehicle segment. It has been a year of milestones, from Blue Origin's first re-launch of its reusable **New Shepard booster** in January and now multiple flights of the single rocket, to United Launch Alliance surpassing the 100 successful launches mark. Sophisticated estimation methods leveraging the Air Force GPS constellation for precision navigation have contributed to successes like SpaceX landing a Falcon 9 first stage intact on a drone ship in April, which was a first. NASA is building toward the Space Launch System vehicles' Exploration Mission 1, which will include a precision lunar flyby of a crewless version of the Orion vehicle.

On July 4, after a five-year journey, a Jupiter orbit-insertion maneuver put the **Juno spacecraft** in a polar orbit around the planet. Over the next 18 months, Juno will orbit Jupiter 36 times, coming in as low as 2,000 kilometers over the surface. Its nine instruments will study Jupiter's atmospheric composition and dynamics, magnetic and gravity fields, and the polar magnetosphere. Juno has already sent pictures of the Jovian northern pole, that "looks like nothing we have seen or imagined before," according to Scott Bolton, Juno's principal investigator. It already shows that Jupiter is nothing like its sibling, Saturn. For a spacecraft with such an ambitious science campaign, its GNC system is rather prosaic — it is passively spin-stabilized at a leisurely 3 rpm — proving that things don't have to be complex to achieve greatness. ★

New digital meshing, computational tools unveiled

BY JAMES MASTERS AND CAROLYN WOEBER

The **Meshing, Visualization and Computational Environments Technical Committee** is concerned with interactive computer graphics systems and their application to aerospace design and computer-aided manufacturing.

Computational analysis continues to be an essential component of the aeronautics and astronautics analysis landscape. The meshing, visualization and computational environments that are necessary to create the structure within which this analysis takes place continue to advance to meet current needs as well as anticipate the needs of the future.

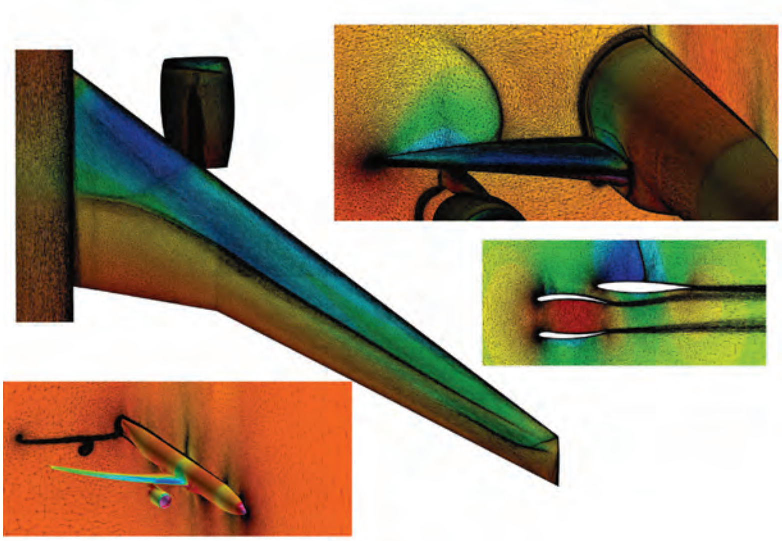
On the commercial meshing side, Pointwise Inc., worked with the U.S. Air Force to improve the integrated overset meshing and assembly tools in their flagship meshing software. Motivated by the need for large configuration management, Pointwise developed a system of hierarchical containers called **Frameworks**, which facilitate flexible model definition, overset meshing and grid assembly. Additionally, a new mesh technique, termed voxel meshing, was used to provide a unique sketch-based interface for rapid off-body meshing. These technologies, which were developed as part of an Air Force-sponsored **Commercialization Readiness Program**, were demonstrated to the Air Force in September and are scheduled for inclusion in an upcoming version of the commercial software. Syracuse University and the Massachusetts Institute of Technology continue to make strides in their collaborative production of **Engineering Sketch Pad**, or ESP, software that will quickly generate geometry for general air vehicle models. These models can be used for initial design studies and parametric analyses. ESP leverages vehicle-generation concepts, which have typically focused on manufacturing, and expands these concepts for the generation of models for aerospace design and multidisciplinary analysis and optimization. This work built on ideas presented in a paper titled **"Design Sensitivity Calculations Directly on CAD-based Geometry,"** which was this year's recipient of the MVCE technical committee's Shahyar Pirzadeh Best Paper Award. Also out of Syracuse came a novel approach for generating parametric geometry models based on existing point clouds. Because many high-fidelity legacy geometries are not readily available, this technique provides an intriguing alternative.

Work continues in the realm of in situ processing in which data is intelligently reduced, analyzed, transformed and indexed while still in memory before being written to disk or transferred over networks. A collaboration between the Defense Department and Intelligent Light brought together Kestrel, the DoD flow solver framework, and the FieldView commercial visualization tool to demonstrate a workflow using in situ data extraction that showed good scalability and acceptable overhead. This workflow produced a fast and flexible methodology that reduced costly communication while preserving data for later analysis and visualization.

Within the computational fluid dynamics community, finite element solvers able to generate high-order solutions are reaching a maturity level where they are becoming serious contenders as tools for solving production-level problems. With finite element solvers becoming more accepted, there is an impending need to generate appropriate computational meshes and adequately visualize resulting solutions. Some initial work has been done on the high-order meshing front by the University of Tennessee and Pointwise that included mesh generation by springfield and vector adding as well as weighted condition number optimization. True production level high-order mesh generation and visualization remains elusive but the need and incentive is clear and resources are being allocated to attack these important problems.

The meshing, visualization and computational environments community continues to be motivated by the finding from NASA's **"CFD Vision 2030 Study"** that mesh generation is a bottleneck in the CFD workflow. To that end, a special session on Vision 2030 goals related to Computational Environments will be held at AIAA SciTech 2017 in Texas.★

▼ Adapted mesh and pressure contours are shown for a solution about the NASA Common Research Model. The picture highlights how the adaptive mesh node distribution, element anisotropy and element orientation efficiently resolve flow field features.



Boeing

Progress on motion cueing, flutter suppression

BY SUNJOO ADVANI, JEFFERY SCHROEDER AND EDWARD BURNETT

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.

Loss-of-control incidents have sharpened the focus on pilot training techniques and tools, including motion cueing in flight simulation. While standards for motion platform hardware testing have existed for decades, industry has struggled with objective measures to quantify motion cueing, which is dominated by software.

The new **Objective Motion Cueing Test**, or OMCT, standardizes testing of both hardware and software. It was included in International Civil Aviation Organization Manual 9625 in the fall of 2014, as well as in an update to FAA simulator regulations in the spring. The OMCT was evaluated and refined by surveying 10 operational training simulators. Overall, the OMCT helped the simulator manufacturers verify or fine-tune the simulator motion cueing characteristics.

One simulator manufacturer claimed the test yielded significant improvements to their simulators and a better understanding of motion cueing issues. In the next step, the OMCT needs to be redefined for rotorcraft simulation.

The FAA has also been investigating motion cueing in pilot training to provide guidance to training operators on simulation fidelity requirements necessary to comply with new pilot training regulations. To this end, the FAA conducted a study in the NASA Ames Research Center's **Vertical Motion Simulator**, or VMS, in California. Sixty-one general aviation pilots trained on four challenging commercial transport tasks under different motion conditions that included typical hexapod motion. The pilots repeated the tasks with large-amplitude VMS motion to assess training effectiveness of the different motion conditions. New objective motion criteria, based on the OMCT, guided the selection of the simulated hexapod motion conditions.

The results indicated that the motion condition used in training affected touchdown position, stall recovery technique, pilot opinion, maximum load factor obtained, and reaction time. The results also suggested the new objective motion criteria may offer standardization benefits, as improvements in the motion fidelity, predicted by the criteria, correlated with improvements in pilot opinion and objective performance measures.

Lockheed Martin Skunk Works

▲ **Lockheed Martin, NASA and the Air Force** Research Laboratory are continuing work on active flutter suppression controls for Lockheed's X-56A aircraft.

In April, the FAA qualified the first flight simulator, a **B737-800**, for use in full stall recovery training at Alaska Airlines. This simulator was updated with a new aerodynamic model developed by Bihrle Applied Research of Virginia, which included an evaluation by a test pilot with hundreds of full stalls in the same aircraft. In July, the FAA qualified a second B737 simulator at Southwest Airlines for full stall training that had an updated aerodynamic model developed by Boeing. This update incorporated data collected during the aircraft certification program but not included in the original simulator model, as full stall training was not required previously in simulation.

Lockheed Martin Skunk Works, the Air Force Research Laboratory and NASA continued to work on active flutter suppression controls for **Lockheed's X-56A aircraft**. Simulation models of the vehicle were correlated with data from the first phase of flight testing in 2013. New model formulations that better represent the flexible aerodynamics and structural dynamics were developed using flight data. These new modeling techniques are an important step in the development of structural mode control that will allow for more efficient aircraft designs. These new technologies will make future flight simulation training devices more representative of the aircraft. The X-56A team is also discussing certification requirements with the FAA for future civil aircraft experiencing active flutter suppression. ★

Plasma research operating on many fronts

BY MICHAEL D. WHITE AND DAVID L. CARROLL

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

Despite a sharp drop in funding for plasma actuator research for aerodynamic control, important progress has been made this year toward viable flow control systems. University of Notre Dame researchers continue in their development of plasma-based vortex generators. These generators help keep the flow attached by thickening the boundary layer. Experimental tests on a **V-22 tiltrotor wing model** showed post-stall drag reduction of up to 40 drag counts.

Researchers at the Air Force Engineering University in China and Xi'an Jiaotong University developed a single-power-driven multichannel discharge **plasma synthetic jet actuator**, or PSJA. Experiments show that a 12-element array results in six times the affected area and 64 percent of the jet velocity of a traditional PSJA.

The U.S. Air Force awarded a $4.8 million contract to Raytheon to continue work on CHAMP, the **Counter-electronics High Power Microwave Advanced Missile**. The CHAMP team includes the Air Force, Boeing, Raytheon and Sandia National Laboratories in New Mexico.

The Air Force Office of Scientific Research awarded a Young Investigator award to a Purdue researcher to study plasma control of flames at high pressures. This research will find its ultimate application in improving gas turbine and rocket engines.

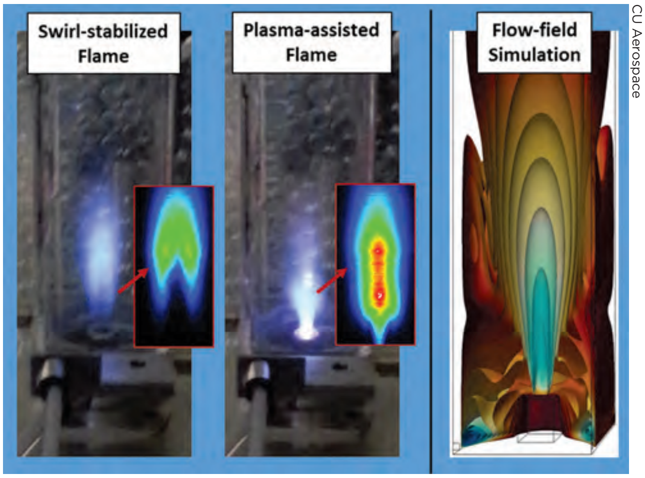
Researchers at the University of Illinois at Urbana-Champaign have teamed up with CU Aerospace, an Illinois small business, to study improvement of methane flame stability near lean blow-off conditions by application of microwave plasma excitation in the flame region. This combined computational and experimental effort directly compares robust 3-D multiphysics simulations of an experimental apparatus with diagnostic measurements of flow field parameters, radical distributions and plasma characteristics.

Princeton University achieved backward lasing from water vapor greater than 40 percent humidity in room air by dissociation of the water molecules with a preliminary laser pulse followed by two photon pumped lasing from the hydrogen atomic fragments. The pump is at 205 nanometers and the lasing is at the hydrogen-alpha line, or 656 nanometers, which is the same color as red laser pointers. The air laser pulses are highly coherent with 10 to 30 picosecond duration and propagate in the forward and backward directions.

The Air Force Research Laboratory demonstrated a flowing **diode pumped alkali laser**, or DPAL, system using a potassium gas mixture with an output laser power of 1.5 kilowatts. The diode pump energy was approximately 3.1 kW, resulting in an optical-to-optical conversion efficiency of 48 percent. These laboratory researchers also demonstrated simultaneous lasing on rubidium and cesium lines in a multiline DPAL, as well as a master oscillator power amplifier configuration.

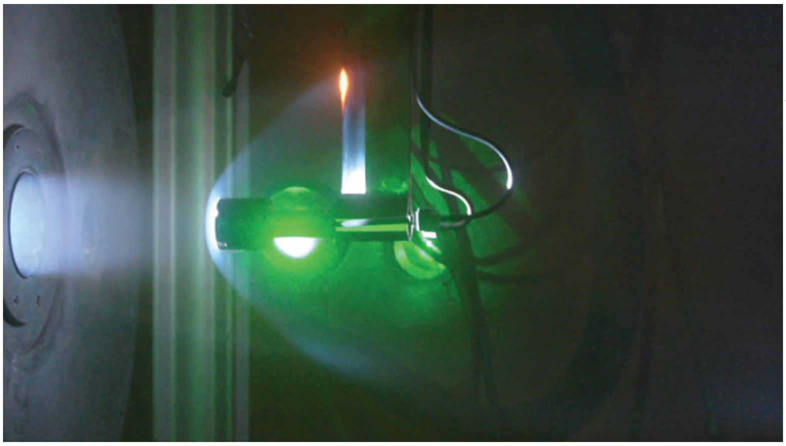
A continuous-wave optically pumped **metastable argon laser** was demonstrated by Emory University of Atlanta, Physical Sciences Inc. and Tufts University, both in Massachusetts, and the Lebedev Physical Institute in Moscow with an optical-to-optical conversion efficiency of 55 percent. High densities of argon were generated in an atmospheric pressure mixture of argon and helium using a linear array of micro-discharges, operating at a frequency near 1 gigahertz. Scaling efforts are underway to make larger volume discharges in high-pressure argon/helium mixtures. Promising results have been obtained using a pair of coupled linear micro-discharge arrays and a dielectric barrier discharge.

Researchers at Ohio State University have demonstrated highly vibrationally excited **carbon monoxide**, or CO, in ground electronic state generated by a chemical reaction between carbon vapor and molecular oxygen. The excited CO is generated at low temperatures, 260 to 350 degrees Fahrenheit, in a collision-dominated environment. The absolute population inversion is measured at molecular vibrational energy levels 4 to 7, having an average vibrational energy per CO molecule formed by the reaction that is at least 10 to 20 percent of reaction enthalpy. These results show the feasibility of developing a new CO chemical laser using carbon vapor and oxygen as reactants. ★



CU Aerospace

▲ **Industry and academic researchers have teamed** on plasma-assisted studies in a swirl-flow reactor. Shown at left is a methane flame image, then with hydroxyl radical concentration measurements. At far right is a reactor flow-field simulation of iso-surfaces colored with turbulent kinetic energy.



German Aerospace Center

Thermophysics advances in many areas

BY JONATHAN BURT AND ALEXANDRE MARTIN

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

▲ **A sample of heat shield material is tested** in the German Aerospace Center, DLR's, arc-heated wind tunnel in Cologne, Germany. Ionization-induced gas emission accounts for the white glow around the nozzle exit on the left and in the post-shock region surrounding the sample.

During the past year, several milestones in aerospace vehicle heat transfer analysis and thermal management were accomplished. These include commencement of an asteroid sample return mission, post-flight analysis from the initial flight of NASA's next crewed spacecraft, advances in testing of thermal protection system (TPS) materials, and new technology development for in-space heating mitigation.

NASA's Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer, or **OSIRIS-REx**, lifted off from the Kennedy Space Center in September with the goal of retrieving a sample from the asteroid Bennu and returning the sample to Earth. The OSIRIS-REx spacecraft leverages the entry, descent and landing system of the sample return capsule from the Stardust mission in 2006. The OSIRIS-REx atmospheric entry speed of 12.2 kilometers per second will be only slightly lower than that of Stardust, which was the fastest spacecraft in history to enter the Earth's atmosphere. Engineers from the NASA Ames Research Center in California provided aerothermal environment analysis, and worked closely with prime contractor Lockheed Martin to confirm the applicability of the Phenolic Impregnated Carbon Ablator material used in Stardust for the OSIRIS-REx mission. Arc jet test facilities at Ames were used to validate and verify the **TPS design** selected for mission implementation.

In June, the 46th AIAA Thermophysics Conference in Washington, D.C., included a thorough multisession review of TPS flight data and post-flight analysis for the first test flight of NASA's Orion **Multi-Purpose Crew Vehicle** in December 2014. For this flight, named Exploration Flight Test 1, the re-entry heat shield was instrumented with thermocouples, radiometers, pressure sensors and ablation sensors. After recovery, the heat shield was removed from the structure, and samples were extracted for post-flight inspection. Detailed analysis of flight data has been performed with the aim of improving the predictive capability of numerical models, thus reducing uncertainty margins. Extensive TPS design and fabrication work has been performed in 2016 for the next Orion mission, Exploration Mission 1, scheduled to launch in September 2018. Diverging from the honeycomb-reinforced material used for the first Orion flight, the heat shield for this second flight will be constructed from molded tiles.

As part of the **Advanced Ablation Characterization and Modelling program** at the German Aerospace Center, a series of TPS material tests has been conducted at the center's L3K arc-heated wind tunnel with the goal of providing detailed validation data for numerical modeling of TPS material response. Ablative materials including carbon phenolic, silica phenolic and cork phenolic were investigated at selected conditions for Earth and Mars entry trajectories. Gas temperature measurements employing the Coherent Anti-Stokes Raman Spectroscopy method provided important data concerning the thermal non-equilibrium behavior in both the freestream and disturbed flow regions around the samples.

The past year has seen significant progress toward effective passive thermal management of next-generation **Gallium Nitride based solid-state power amplifiers**, or GaN SSPAs, for use onboard spacecraft. Next-generation GaN SSPAs are expected to reach heat fluxes well beyond the limitations of current thermal management techniques, and the full potential of these devices can be realized only through development of new cooling systems with minimal size, weight and power requirements. In collaboration with the Air Force Research Laboratory, small businesses ThermAvant Technologies of Missouri and Advanced Cooling Technologies of Pennsylvania demonstrated passive thermal management devices capable of spreading GaN SSPAs heat loads for transport through conventional heat pipes to spacecraft radiators. ThermAvant Technologies implemented innovative microchannel patterns and high performance working fluids in a novel heat spreader design. Advanced Cooling Technologies used new wick configurations and an internal locking feature to develop a high heat flux vapor chamber with low thermal resistance. ★

Contributors: *Ali Guelhan, Mairead Stackpoole, Brent Taft*

Trainer makers compete; many aircraft take first flights

BY MICHAEL L. DRAKE AND MICHAEL J. LOGAN

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


NASA

▲ **An artist's concept** shows NASA's X-57 Maxwell, set to advance integrated electric propulsion for passenger flight.

The year was busy for aircraft development across many sectors of the industry. The U.S. Air Force's T-X advanced pilot trainer has multiple manufacturers competing. Lockheed Martin, along with Korea Aerospace Industries, is upgrading the T-50. Raytheon's T-100 entrant is a development of Leonardo-Finmeccanica's M-346. There were also two new entrants. Northrop Grumman, BAE Systems and L-3 revealed a prototype (built by Scaled Composites) in August, and the Boeing/Saab team rolled out not one, but two airframes Sept. 13. Other military programs of note included China's large four-engine airlifter, the **Avic Y-20**, entering service. Boeing's KC-46 continued flight testing that led to award of low-rate initial production. The U.S. Air Force declared the F-35A basic combat-ready in August.

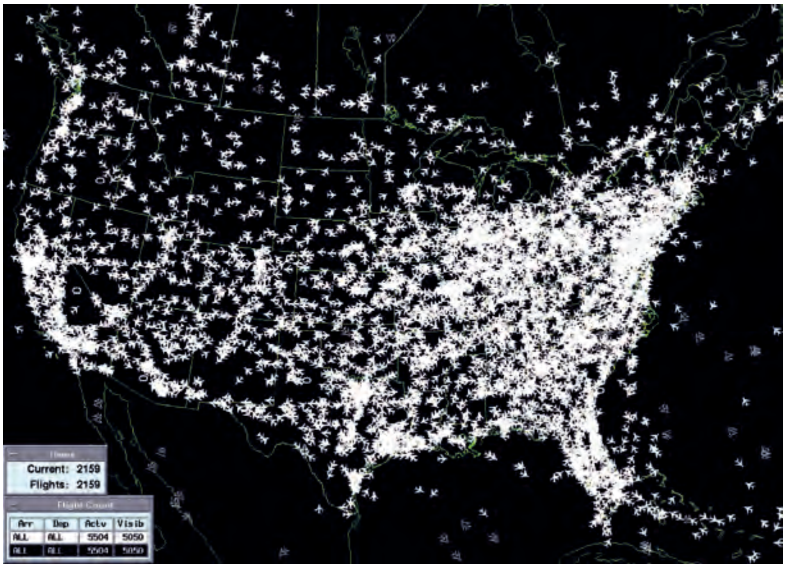
Numerous advanced technology initiatives made progress. Japan's X-2 stealth technology demonstrator achieved first flight in April. South Korea launched a five-year technology demonstrator program for unmanned strike aircraft. DARPA's vertical takeoff and landing experimental plane, or VTOL X-plane, efforts continued, with Virginia-based Aurora Flight Sciences granted development of the **LightningStrike**, a tilt-wing, distributed hybrid electric propulsion vehicle targeting high-speed and VTOL capabilities. Northrop Grumman commenced wind tunnel testing of its tail-sitting VTOL concept for DARPA's TERN program.

Single-aisle commercial transport development was incredibly active. The A320neo, with Connecticut-based Pratt & Whitney engines, was delivered to Lufthansa on Jan. 20. Boeing's first flight of the **737 MAX** was Jan. 29. The A321neo's first flight, powered by CFM engines, was Feb. 9. Embraer rolled out its first E-Jet E2, an E190-E2, in February. The Pratt & Whitney geared turbofan-powered aircraft had its inaugural flight in late May. The Russian Irkut MS-21-300 variant rolled out in June. Comac's ARJ21 entered service in June with Chengdu Airlines. Bombardier's C Series also entered service, with the CS100 variant delivered to Swiss Global Air Lines in July. Its larger sibling, the CS300, obtained Transport Canada certification the same month.

In General Aviation, Austria's Diamond Aircraft Industries flew its **DART-450 Turboprop** on May 17. Tecnam's P2012 Traveler's first flight was July 21. The Cessna Citation Longitude, a super-midsized business jet, first flew in October.

In civil research, NASA reported the results of its multiyear Environmentally Responsible Aviation Project, aimed at advancing technologies for more efficient commercial transports. A wide variety of technologies and concepts were examined indicating that substantial advancements in fuel efficiency, lower carbon dioxide and oxides of nitrogen emissions, and improved community noise are all feasible. With this, NASA began shifting focus on developing X-planes to further technology readiness. Its **X-57 Maxwell**, under the Scalable Convergent Electric Propulsion Technology and Operations Research, or SCEPTOR, program, is a manned, electrically powered, multiple propeller wing aircraft. NASA moved forward with its Quiet Supersonic Technology low-boom flight demonstrator with an award to Lockheed Martin's Skunk Works. NASA granted additional X-plane development contracts to support concept development for its Ultra Efficient Subsonic Transport Thrust.

Advancements in electric-based propulsion aircraft abounded. Switzerland's **Solar Impulse 2** completed its 16-month round-the-world circumnavigation by an all-electric manned vehicle, upon landing in Abu Dhabi, United Arab Emirates, in July. NASA, along with SCEPTOR, also explored hybrid electric propulsion concept work. In April, Airbus and Siemens announced they signed a cooperation agreement to develop prototypes of hybrid-electric propulsion systems for future commercial transports. Among many small electric vehicles in development, Germany's E-Volo VC200 multicopter, a two-seat VTOL, had its inaugural flight in March. The FAA's new Part 107 for unmanned aircraft under 55 pounds (about 25 kilograms), is expected to unleash a proliferation of vehicle design, electric or otherwise, in this rapidly developing market niche. ★



FAA

FAA finalizes rules for small drones

BY KAREN MARAIS, JOHN KOELLING AND MARK BALLIN

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

▲**The FAA finalized rules** for small drones in 2016, and research continues for safely integrating all drones into the nation's airspace.

Data made available this year showed U.S. domestic passenger boarding increased by 5 percent from 2014 to 2015. Load factors continued to hover around 83 percent, with domestic flights being slightly higher on average. Passengers seemed less unhappy with airlines: Complaints to the **Department of Transportation Aviation Consumer Protection Division** for the first six months of 2016 were 12.2 percent lower than the same period in 2015. Cancellations were at 1 to 2 percent of flights, and year-on-year on-time arrivals are slowly improving. Weather continues to be the largest reported cause of delays.

Airline accidents continue to trend downward in terms of 10-year moving average. In 2015, there were 560 fatalities across 16 accidents worldwide, and through Sept. 1, 2016, there had been 182 fatalities from 10 accidents. Aircraft continue to experience laser strikes that distract pilots and potentially cause eye injury. In the U.S., incidents reported to the FAA in 2015 almost doubled compared to 2014 to over 7,700, and 2016 is on pace to exceed 2015 values.

In July, the FAA finalized the first operational rule for routine commercial use of small unmanned aircraft systems, opening pathways toward fully integrating drones into the nation's airspace. The rule provides safety regulations for small unmanned aircraft weighing less than 55 pounds (about 25 kilograms) that are conducting non-hobbyist operations.

The FAA has also implemented all 24 of the **Automatic Dependent Surveillance-Broadcast**, or ADS-B, en-route baseline radio stations in the continental U.S. and Alaska and is on track with terminal area and surface installations. Because the 2020 ADS-B "Out" mandate is targeting more than 16,000 aircraft to be equipped in the next four years, there is concern about whether the industry can meet a last-minute avionics demand.

In July, the FAA awarded a $344 million contract to Lockheed Martin to develop the **Terminal Flight Data Manager**, with initial operating capability expected around 2020. TFDM will provide capabilities to allow controllers to manage flights on the airport surface and terminal area and allow future integration with other FAA automation systems.

Flight operations research continues to be strong, especially trajectory-based operations and the integration of drones into the National Airspace System. In 2015, more than 1,000 people from industry, academia and government attended the inaugural **Unmanned Aircraft Systems Traffic Management Convention** at NASA's Ames Research Center in California. Both Google and Amazon, for the first time publicly, presented their concepts and plans on future operations. The 2016 convention was scheduled to take place in Syracuse, New York, in November.

NASA transferred the **Terminal Sequencing and Spacing software** to the FAA in July. TSAS provides suggested speeds controllers should assign to aircraft as they follow fuel-efficient, continuous-descent arrival procedures and enables routine use of performance-based navigation procedures, resulting in fewer course and altitude changes while also reducing the frequency of communications. The FAA is looking to implement these tools operationally within the next five years.

The **NASA Aeronautics Research Mission Directorate** has developed roadmaps for six strategic thrusts defined in its strategic implementation plan, released in 2015. Three of the six thrusts focus on advancing aviation operations: Strategic Thrust 1: Safe, Efficient Growth in Global Operations; Strategic Thrust 5: Real-Time System-Wide Safety Assurance; and Strategic Thrust 6: Assured Autonomy for Aviation Transformation. The road maps identify research needs and potential NASA activities to achieve advances in operations and enabling technology over this period.

Finally, the growing awareness in the aviation community of the obstacles presented by complex and integrated software is resulting in more research into developing alternate certification methodologies and tools to ensure validated safety claims. Efforts to coordinate this work among distinct organizations have started and continue to grow. ★

Contributor: *Tom Reynolds*

FAA reaches NextGen, unmanned air milestones

BY DAVID THIPPHAVONG

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

NASA

▲ **NASA's Ikhana** unmanned aircraft system, front right, and five conventionally piloted aircraft were flown in flight tests to validate standards for detect-and-avoid systems.

The global airline industry continued to grow in 2016, with profits projected to increase from $35.3 billion in 2015 to $39.4 billion in 2016, according to the International Air Transport Association. Leading the charge is North America, where profits are expected to be $22.9 billion in 2016, with a 10.8 percent net post-tax profit margin that exceeds the peaks of the late 1990s. Key factors driving this strong performance include lower fuel prices, higher load factors of passengers and cargo due to consolidation of commercial airlines and rising revenue from ancillary sources, such as baggage fees.

In the United States, the FAA achieved significant milestones for the **Next Generation Air Transportation System**, or NextGen. The **En Route Automation Modernization**, or ERAM, system, completed in March 2015, facilitates many NextGen capabilities that will increase airspace capacity through more accurate tracking of aircraft using satellite-based technology (Automatic Dependent Surveillance-Broadcast) and improve flight efficiency through more direct routes and more precise weather avoidance while continuing to ensure safety. ERAM also enables Data Communications, or Data Comm, services that allow pilots and air traffic controllers to exchange flight instructions, requests and reports using digital text-based messages. Besides preventing the "talk back, read back" errors that can occur by voice, Data Comm will expedite communications, resulting in estimated delay reductions of 6 to 12 minutes and estimated fuel savings of about 100 gallons of fuel per flight on average. Data Comm is on track to be deployed in 56 of the nation's major airports by the end of 2016 — 2½ years ahead of schedule.

The FAA also made significant steps toward enabling routine unmanned aircraft operations in U.S. skies. The administration released draft rules for small **unmanned aircraft systems**, or UAS (less than 55 pounds, or about 25 kilograms), in 2015 to great interest throughout industry, government and academia. Following a comment and review period, the FAA finalized the first operational rules for routine commercial use of small UAS in June 2016. Those rules went into effect at the end of August. The proposed regulations would allow operators to fly small UAS during daylight hours, within visual line of sight, at speeds no greater than 100 mph (about 162 kph) and at altitudes no higher than 400 feet. Prospective operators who wish to obtain the required pilot airman certificate with a small UAS rating must be at least 16 years old, pass a Transportation Security Administration background check and demonstrate aeronautical knowledge through testing or flight review. The FAA estimates that 600,000 small UAS will be used commercially within the next year.

In a separate effort, a group of government, industry and academic institutions is working under RTCA to develop minimum operational performance standards for larger UAS. A preliminary document for **detect-and-avoid**, or DAA, systems was released in 2015 with the final version on track to be completed by December 2016. DAA systems enable UAS to satisfy federal aviation regulations to remain "well clear" of other aircraft. Between April and June, NASA, the FAA and industry partners Honeywell and General Atomics Aeronautical Systems performed flight tests at NASA's Armstrong Flight Research Center in Southern California to validate the minimum operational performance standards. Over 260 encounters between NASA's **Ikhana unmanned aircraft system** and a wide range of manned aircraft types and capabilities were flown. The flight tests demonstrated that NASA's representative DAA algorithms were able to provide the precise alerts and guidance necessary for the UAS pilot to maintain safe separation from other aircraft. ★

Expanding reach, capabilities of balloon systems

BY DEBORA FAIRBROTHER, CHRISTIAN LOCKOWANDT AND KURT SEHNERT

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.

NASA

▲ **A NASA super-pressure balloon** carrying the Compton Spectrometer and Imager gamma ray telescope prepares for launch in Wanaka, New Zealand in July.

The mission capabilities of balloon systems have expanded significantly with the advent of new materials, computational skills and conceptual designs. Long-duration flight, altitude control and navigation have become major areas of focus across the field.

A 532,200-cubic-meter superpressure balloon launched in July in New Zealand carried the NASA-supported **Compton Spectrometer and Imager gamma ray telescope** for 46 days at approximately 110,000-feet altitude before being terminated on command in Peru. Another balloon, launched in January, was NASA's latest launch of a long-duration balloon in Antarctica. In June, NASA re-established the Columbia Scientific Balloon Facility in Palestine, Texas, as a launch site with a balloon-borne imaging telescope mission. This campaign expands night-time heavy-lift flight opportunities. Still another campaign, in Fort Sumner, New Mexico, combined science, technology and educational missions, including the High-Altitude Student Platform and X-Calibur, an instrument that utilizes the Wallops Arc-Second Pointing system to observe mass-accreting black holes and neutron stars.

Google's **Project Loon** tested balloons at the McKinley Climatic Lab at Eglin Air Force Base, Florida, validating its design down to temperatures as low as minus 60 Celsius. One balloon flew for 190 days: It launched from Puerto Rico and went across Africa and over the Indian Ocean before being denied overflight permission in Indonesia; it then flew west to South America and landed within 20 kilometers of Winnemucca, Nevada. These long flights are providing valuable real-world data, testing navigational capabilities and allowing researchers to study the effects of ultraviolet light on the envelope materials.

South Dakota-based Raven Aerostar has initiated an internal program to develop a new generation of stratospheric balloons. To demonstrate directional control, three of these super-pressure balloons were launched from Bend, Oregon. After traveling over 1,800 kilometers with trajectories diverging by hundreds of kilometers, the balloons were maneuvered and terminated in March with the payloads all landing within a 4-km radius.

World View secured private financing for its new 12,500-square-meter global headquarters and stratospheric balloon manufacturing facility in Arizona, adjacent to Spaceport Tucson. Among other major projects, World View is developing **Stratollite**, a new altitude-controlled vehicle designed to provide persistent regional coverage for payloads up to 100 kilograms. World View announced a collaboration with Colorado-based Ball Aerospace to demonstrate the Stratollite platform for commercial remote-sensing applications and was awarded two new NASA Flight Opportunities Program contracts to conduct high-altitude balloon missions in 2016 and 2017.

In Europe, the Swedish Space Corp. launched the **Polarized Gamma-ray Observer mission** from Esrange Space Center near Kiruna, Sweden. This collaborative project between Swedish and Japanese scientific teams measured the polarization of soft gamma rays in the 25-80 kiloelectron-volt energy range. Using a modified design from 2013, the balloon flew a 2,000-kilogram gondola for approximately seven days at an altitude of 129,000 feet, landing in northern Canada. CNES, the French space agency, conducted its scientific zero-pressure balloon campaign and tested its new telemetry tracking and control system with two launches from the Swedish Space Corp. balloon facility at Esrange.

Smith College in Massachusetts conducted two campaigns utilizing its **altitude-controlled meteorological balloons**. With support from Finland's Aboa station and the Meteorological Institute of Norway, one of the 300-gram balloons flew for 65 hours in Antarctica, performing repeated soundings from the ice surface to an altitude of 12,000 feet and navigating shallow atmospheric layers. A Department of Energy-funded project with SUNY Albany in New York and the Universidade Federal do Oeste do Para in Brazil supported nine balloon flights in the Amazon tracking river-induced circulations and measuring evolving atmospheric profiles over the undeveloped rainforest. ★

Contributors: *Andre Vargas and Paul Voss*

The changing face of flight testing

BY KARL GARMAN AND ANDREW FREEBORN

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


Solar Impulse

▲ **The Solar Impulse 2** demonstrated a zero-fuel global flight capability in 2016.

Key events of 2016 evidenced the flight testing community's adaptive moves into nontraditional fields, vehicles and facilities.

In July, the two pilots of the Swiss **Solar Impulse 2** aircraft completed their multistop, around-the world flight, when the aircraft landed in Abu Dhabi, United Arab Emirates. The zero-fuel aircraft demonstrated the capabilities of combining solar-electric technologies, lightweight means of construction and in-flight energy management strategies.

Nontraditional entrants continue to emerge in the unmanned aircraft systems, or UAS, field. Most notably are companies with information technology as their core business focus. Facebook exemplifies this trend with its solar-powered **Aquila UAS**, which first flew June 28 in Yuma, Arizona. The company's vision is to use high-altitude and high-endurance UAS to broadcast internet services to currently underserved portions of the world.

NASA and its international partners completed a novel flight test, not of a vehicle, but of the human body. **Astronaut Scott Kelly** returned to Earth in March after 340 days on the International Space Station. His identical twin, retired astronaut Mark Kelly, acted as the experiment control to help find differences between living on Earth and in space. NASA anticipates that data from the twins' experiment will help us understand the human factors of long-duration spaceflight and how to design systems and procedures to enable such missions.

NASA also conducted blended manned/unmanned flight tests in support of UAS airspace integration. The Flight Test Series 4 program involved tests of a **"Detect and Avoid,"** or DAA, guidance algorithm. This work supported the validation of DAA minimum operational performance standards and collaboratively involved General Atomics Aeronautical Systems, Honeywell and RTCA, based in Washington, D.C. The flight tests were executed over 260 unique air-to-air encounters during a nine-week period. NASA tested its Ikhana UAS, equipped with a representative DAA system, against multiple role-playing intruder aircraft. DAA is essential to safe UAS integration into the National Airspace System, for which this project generated copious data.

In airborne sciences flight testing, NASA used an F/A-18 to generate sonic booms during research flights aimed at determining how low-altitude turbulence affects the loudness of sonic booms as heard on the ground. The **Sonic Booms in Atmospheric Turbulence project** utilized three ground microphone arrays, an instrumented TG-14 motor glider to measure the boom level and weather-recording equipment to characterize the atmosphere. Twenty flights were flown at Edwards Air Force Base, California, July 11-22.

Several distributed hybrid electric propulsion projects are entering their flight testing phases. An evident example is the April 18 test of the Virginia-based Aurora Flight Sciences' 20 percent subscale demonstrator for its DARPA-funded **LightningStrike vertical takeoff and landing experimental plane**, or VTOL X-plane. Aurora anticipates the full-scale VTOL X-plane to be the first aircraft to demonstrate a synchronous electric-drive system with distributed hybrid-electric ducted fan propulsion, providing high efficiency in both hover and high-speed forward flight.

The FAA reauthorization bill extended the use of the UAS testing facilities, with the six sites now authorized through September 2019. These sites support the work of the FAA's **William J. Hughes Technical Center** in New Jersey. The center collects data for both safety-related and capability improvements to the National Airspace System.

Two rotorcraft flight-test accidents, with two fatalities apiece, set back their respective visible projects. The AgustaWestland **AW609 civil tiltrotor** prototype crashed in northern Italy while performing high-speed tests in October 2015. The aircraft had been due to complete its flight-test program by the end of 2016. Bell Helicopter's experimental 525 "Relentless" vehicle was conducting developmental flight tests July 6 near the company's Texas facility. As of this writing, both accidents remain under investigation by respective authorities. ★

Contributors: *Starr Ginn, Bruce Owens and Brent Cobleigh*

Large deposit of helium gas found in Tanzania

BY ALAN FARNHAM

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

In August, Hybrid Air Vehicles' **Airlander 10** emerged from its Cardington, England, hangar, and made its first test flight, a brief 19-minute excursion. On Aug. 24, Airlander undertook a second test flight, remaining aloft 100 minutes before returning to base, where it sustained a slow-motion, nose-down heavy landing that left the front of its flight deck damaged. Pilots and ground crew were unharmed. HAV says both the damage and causes for the incident are being assessed and that it expects Airlander to fly again in early 2017.

In March, Lockheed Martin announced that Atlanta-based Hybrid Enterprises, the exclusive reseller for Lockheed's 20-ton capacity **LMH-1 hybrid airship**, had signed a letter of intent with English aircraft operator Straightline Aviation, or SLA, under which SLA can acquire up to 12 hybrid airships for a reported price of $480 million. In August, Hybrid Enterprises announced that a partnership between SLA and Alaska's PRL Logistics will operate, starting in 2019, LMH-1 airships out of Kenai, Alaska, for clients in mining, oil and gas, construction and other industries. Lockheed has built a full-scale prototype LMH-1 gondola that includes a cargo bay, fuel bay, flight deck and cabin for 19 passengers. The company also unveiled Spider, a self-propelled robot that can autonomously find and patch tiny pinholes in airship envelopes.

In June, the University of Oxford and Norwegian exploration company Helium One announced the discovery of a significantly large deposit of helium gas in Tanzania. The deposit, only one of what the researchers believe to be many, contains a probable resource of about 1.5 billion cubic meters. By comparison, the **U.S. Federal Helium Reserve** currently holds 685 million cubic meters, and total known U.S. reserves are 4.3 billion cubic meters. Global helium consumption is running about 227 million cubic meters a year.

Dueling aerostats provided protection for the Rio Olympics: The Altave Omni system by Brazilian aerospace manufacturer Altave, using Virginia-based Logos Technologies' Simera cameras, represented the first use of a wide-area persistent surveillance aerostat for civilian use. Tethered at 200 meters, it captured 360-degree, high-definition images of an area of up to 40 square kilometers. Airship do Brasil deployed a rival system, ADB-A-150, equipped with a gyro-stabilized 3-gimbal SHAPO camera. ADB says it separately is developing and building a 50-meter long, 20-meter tall airship, ADB-3-X01, capable of carrying payloads of up to 2 tons. Also in development is a cargo airship, ADB-3-30, which would carry 30 tons.

The Aerial Delivery Research and Development Establishment of India's Defense Research and Development Organization announced in May the introduction of its **Nakshatra aerostat system**, with a surveillance range of up to 100 kilometers. It is intended for use by military clients, including both the Indian army and India's border security force. A second-generation model, with a surveillance range of up to 250 km, is in development.

Hybrid Air Vehicles

▲ **Cardington, England:** Airlander 10 makes its first flight.

China, via People's Daily Online, said in October 2015 it had test-flown an unmanned, high-altitude, solar-powered 18,000-cubic-meter airship over Mongolia. The craft, jointly developed by Nanjiang Space and Beijing University of Astronautics and Aeronautics, reportedly flew for 22 hours and reached a peak altitude of 65,000 feet.

Goodyear's second German-made Zeppelin NT airship (LZ N07-101), or **"Wingfoot Two,"** made its inaugural flight in March after undergoing final assembly at Goodyear's Wingfoot Lake, Ohio, hangar. It eventually will be based in Carson, California, replacing Goodyear's "Spirit of America" blimp. Assembly of Goodyear's third (and final) Zeppelin NT is scheduled to begin in January. ★

Royal Air Force

Vertical flight continues to grow

BY ERASMO PIÑERO

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

▲ **A Royal Air Force F-35B** flies over RAF Marham in Norfolk, England, the future home for British F-35Bs.

Following last year's U.S. Marine Corps announcement that initial operating capability, or IOC, had been reached for the F-35B version of the Joint Strike Fighter program, the U.S. Air Force announced in August that its **F-35A variant** also reached IOC. With the IOC announcement by the largest F-35 operator, the program has reached a level of maturity not seen on a major fighter program since the days of Lockheed Martin's F-22. The F-35 has already crossed the Atlantic Ocean in both directions and this summer conducted highly publicized appearances at two major air shows in the United Kingdom: the Royal International Air Tattoo and the biennual Farnborough air show. While at Farnborough, one Royal Air Force F-35B demonstrated its powered lift capabilities. On the operational side, the F-35C completed its third aircraft carrier deployment.

The **Bell Boeing V-22 program**, fresh from receiving an order of 17 V-22s from the Japanese Ministry of Defense (its first foreign military sale), received a 44 CMV-22B order from the U.S. Navy to replace the Grumman C-2 Greyhound for carrier onboard delivery. The V-22's 463 kph cruise speed and vertical takeoff and landing capabilities add a new dimension to the Navy's logistical mission, which until now required fixed-wing aircraft and helicopters. The V-22 program introduced an improved engine inlet air filter to protect the engines during austere landings, significantly extending the life of its two turboshaft engines when operating in challenging, austere locales.

The U.S. Army Aviation and Missile Research Development and Engineering Center's **Joint Multi-Role Technology Demonstrator**, or JMR-TD, program continues. The Bell V-280 Valor test article assembly is taking place in Amarillo, Texas, where its wing was mated to its fuselage in April. First flight is expected late next year. Sikorsky Aircraft continues its flight-test program of its S-97 Raider helicopter prototype, a compound helicopter designed and built with company funds intended in part as a risk reduction demonstrator for the JMR-TD program. Sikorsky completed assembly on its second S-97 prototype in 2015.

The Italian company Leonardo-Finmeccanica added another **AW609 tiltrotor test vehicle** to its flight-test program. This third prototype began ground runs in May. The investigation on the crash of the second prototype continues. An accident report should be released next year. Test-flying of the first prototype resumed in the U.S.

The FAA outlined the first drone regulations for operation in the U.S. airspace this summer, highlighting electrical-powered lift and its application to unmanned aircraft. The FAA and other agencies expect the drone market to grow in the next 10 years, contributing $82 billion to the U.S. economy and creating more than 100,000 jobs. In drone technology development, a scaled-down experimental plane design sponsored by DARPA first flew. The 20-percent-to-scale tilt wing has a series of hybrid-electric duct fans buried in its tilting wing and canard surfaces. The engine selected for a final full-scale version is the same engine used on the V-22. The unmanned aircraft, named **LightningStrike**, was designed and manufactured by Aurora Flight Sciences, a company headquartered in Manassas, Virginia. ★

Profits dip in aerospace, defense sectors

BY VENKATESAN SUNDARARAJAN

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

▲ **Economical space launch:** United Launch Alliance and Blue Origin in February announced a partnership with the U.S. Air Force to develop Blue Origin's BE-4 engine for ULA's Vulcan launch vehicles. A BE-4 is shown in a combustion test.

The **global aerospace and defense sectors** recorded revenue of $699 billion in 2015 compared with $713 billion in 2014, a decline of 2 percent primarily due to the strengthening of the U.S. dollar, according to the "Aerospace & Defense 2015 year in review and 2016 forecast" report published by PricewaterhouseCoopers in January. The two sectors' operating profits were $65 billion, a decrease of 9 percent from $71 billion in 2014. In constant U.S. dollars, global aerospace and defense sector growth was 3.8 percent in 2015, outperforming global gross domestic product growth of 2.4 percent, according to Deloitte's "2016 Global aerospace and defense sector performance study," published in June.

The commercial aerospace subsector revenues grew 6.3 percent, from $306.2 billion in 2014 to $325.5 billion in 2015. Commercial aircraft delivery was at a record high of **1,397 aircraft** in 2015. As of August, Boeing had delivered 491 jetliners compared to 400 deliveries by Airbus.

The sector recorded merger and acquisition deals worth $54.6 billion in 2015. During the first half of 2016, $13 billion in merger and acquisition was realized through 18 deals that disclosed each had a value greater than $50 million. In January, Virginia-based **Leidos Holdings** initiated a $5 billion deal to acquire Lockheed Martin's Information Systems and Global Solutions business. The largest buyout in the second quarter of 2016 was TransDigm's acquisition of ILC Holdings for $1 billion.

According to the International Air Transport Association, passenger air traffic increased by 5.9 percent year-on-year in July. The 2016 midyear IATA economic report forecast for the commercial airline industry showed revenue of $709 billion and net profit of $39.4 billion. Airlines and their customers are forecast to generate **$118 billion** in government tax revenue for all of 2016.

In the general aviation industry, airplane shipments fell 4.5 percent to 970 units for the first half of 2016, and airplane billings declined 11 percent to $9.3 billion, compared to the same period a year ago, according to the General Aviation Manufacturers Association. Global business jet shipments in the first six months of 2016 totaled 292, a decrease of 4.3 percent from the same period in 2015. Rotorcraft shipments decreased from 467 to 392 units, and billings were down an estimated 32.5 percent to $1.4 billion for the first six months of 2016.

In 2015, the global space economy totaled $323 billion worldwide, according to "The Space Report 2016" by the Space Foundation. Commercial space activities made up 76 percent of the global space economy, valued at **$246 billion**. The U.S. government spent $45 billion on defense and nondefense space efforts in 2015, a 3 percent increase from 2014. The NASA budget for fiscal 2016, which ended Sept. 30, was $19.285 billion, including earlier supplemental appropriations funds, compared to an actual budget of $18.01 billion for fiscal 2015.

NASA awarded a total of $16.63 billion in contracts for fiscal 2015, up 6.5 percent from $15.61 billion a year earlier. Boeing ($1.988 billion), CalTech ($1.864 billion), Lockheed Martin ($1.532 billion), Orbital ATK ($755 million) and SpaceX ($642 million) were the leading contract recipients from NASA. The Russian Space Agency was the largest foreign contractor for NASA, valued at $460 million.

United Launch Alliance and **Blue Origin** announced their partnership with the U.S. Air Force in February to develop the BE-4 engine to power the Vulcan, ULA's next-generation rocket. In April the Air Force awarded an $82.7 million contract to SpaceX to launch the service's next-generation GPS satellite in 2018. In July, SpaceX received the fourth and final guaranteed Commercial Crew Transportation Capability contract from NASA. Boeing received its two orders in May and December 2015, and SpaceX received its first order in November 2015.

In the commercial aerospace sector, growth in travel, primarily in China, India and the Middle East, as well as the need for more fuel efficiency continue to drive demand for new aircraft. International demand for defense and military products is expected to increase due to regional tensions in the Middle East, Eastern Europe, the Korean peninsula, the Indian subcontinent, and the East and South China seas. ★

A century ago, aviation became an industry

BY KEVIN BURNS

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

One hundred years ago, aviation was just coming of age as the Great War had spread across Europe over the previous two years, and the integration of aviation into combat for the first time was seen as a way to break the stalemate of trench warfare.

In 1916 under the guidance of **William "Bill" Boeing**, a tiny airplane manufacturing company was started and grew into a huge corporation of related industries. **Clyde Cessna** also started building airplanes in Wichita, Kansas, during the winter of 1916-17. Today, more than one-fifth of America's civilian aircraft are built in Wichita or by companies from there.

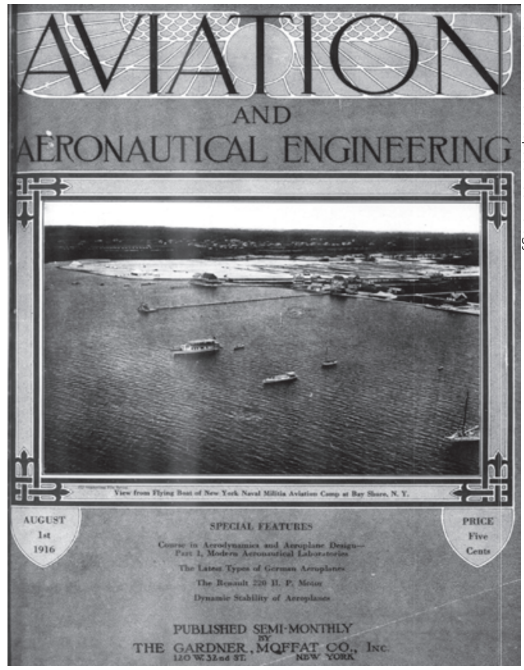
Also in 1916, U.S. Coast Guard Lt. Norman B. Hall borrowed a Curtiss flying boat from the Curtiss Flying School in Newport News, Virginia, for patrol, search and rescue experiments, thus marking the dawn of **Coast Guard aviation**.

In France, the Dassault company celebrated its 100th anniversary this year. Company founder Marcel Dassault designed the Éclair propeller used on aircraft that were flown in the first "air battle" over Verdun in World War I.

In August 1916, Lester D. Gardner, who in 1928 would go on to found the **Institute of the Aeronautical Sciences**, one of AIAA's predecessor organizations, published his first issue of the magazine titled Aviation and Aeronautical Engineering. The magazine cost 5 cents and some of the special features included a course in aerodynamics and aeroplane design, as well as the latest types of German aeroplanes. For a while it served as the journal of the aviation community and then became what is now Aviation Week and Space Technology.

Communities across America celebrated aviation centennial events in 2016. The Nebraska National Guard Museum in Seward installed a new exhibit to commemorate **Ralph McMillen of the Nebraska National Guard**, who died at age 27 in September 1916 while barnstorming in a 1913 Curtiss Model D "Pusher."

Hagerstown, Maryland, celebrated its first manufactured aircraft. In 1916, Giuseppi Bellanca designed, built and tested the Bellanca CD. Fifteen years later, Hagerstown would become the home of Fairchild Aircraft when it moved from New York.



Aviation Week and Space Technology

Lester D. Gardner published the first Aviation Week magazine 100 years ago.

In 1916 the Austin Company in Cleveland received a contract to build the **Curtiss Aeroplane and Motor Company** plant in Buffalo, New York. Over the next century the Austin Company would build other aircraft manufacturing facilities, as well as design and construct hangars, maintenance facilities, and administration and terminal buildings across America.

The National Park Service celebrated its centennial as it preserves aviation history at the Wright Brothers National Memorial in the Dayton Aviation Heritage National Historical Park in Ohio and the Tuskegee Airmen National Historic Site in Alabama.

The space community also celebrated milestones this year with the 40th anniversary of the opening of the Smithsonian Institution National Air and Space Museum in Washington, D.C., and the commemoration of the July 1976 touchdown of the **Viking 1 planetary lander** on the Chryse Planitia, or Golden Plains, of Mars after a voyage of nearly one year. The primary mission of the Viking project ended in November 1976, although the Viking spacecraft continued to transmit to Earth for six years after first reaching Mars.

2016 was also the 50th anniversary of the first orbital docking and of the **Surveyor 1** landing on the moon. Surveyor 1 transmitted more than 10,000 high-quality photographs of the lunar surface and was the first American spacecraft to soft-land on the moon. ★

A year that caught public's notice

BY R. STEVEN JUSTICE

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

Many major events in the aviation and space sectors enthralled the public in 2016 and exemplified how aerospace technology continues to impact our world. Several stories captured attention from the general public and demonstrated the power of technology to inspire while also sometimes illustrating the challenges inherent in introducing new technologies.

One impact is readily demonstrated by the ongoing expansion of unmanned aircraft system operations. The FAA issued its first rules for the commercial operations of small UAS, resulting in over 1,000 applications for "remote pilot" certificates in the first month. "We are part of a new era in aviation, and the potential for unmanned aircraft will make it safer and easier to do certain jobs, gather information, and deploy disaster relief," said U.S. Transportation Secretary Anthony Foxx.

But while many welcome UAS operations, others remain concerned over privacy and safety issues. Kentucky Republican state representative Diane St. Onge said in USA Today in July that "I am alarmed by media reports that the FAA predicts that between **10,000 to 30,000 drones** could be lurking in our skies by 2020." In fact, the registrations of UAS — more than 325,000 — eclipsed that of manned aircraft within the U.S. in 2016. The National Conference of State Legislatures recently reported that eight states have enacted legislation to control the use of drones, with 35 others considering it. But as Baseline magazine stated, "it's apparent that drones are here to stay and will impact a wide swath of industries. The resulting disruption will be enormous — and this is just the beginning."

Big events in spaceflight continue to draw public interest both in traditional and social media. The first successful landings of rocket boosters by both SpaceX and Blue Origin generated 5 million views each on YouTube with subsequent landings drawing millions more views. The **Falcon 9** prelaunch explosion in September also drew 5 million-plus views, and according to the Los Angeles Times, "planned launches of communications satellites that support international mobile phone service and digital television are delayed and put in doubt" — a very real-world impact for consumers.


Solar Impulse

▲ **Solar Impulse 2 in July** completed its multistop circumnavigation of the world on solar power.

Astronaut Scott Kelly's yearlong stay at the International Space Station not only expanded our knowledge of the physical impact of zero gravity but also captured social media attention as described on LinkedIn Pulse by Bob Mitchell: "As Scott's Year In Space captured the world's attention, it was truly those micro-moments captured through Twitter, Instagram and Facebook of his journey that emotionally connected millions to his story in real time." Planetary missions, such as NASA's Juno probe, which entered Jupiter's orbit this summer, generate positive media attention. ABC News posed the question "why should you care" and answered it this way: "Understanding what makes Jupiter tick will help us better understand how our solar system — and others — evolved."

Environmental issues face aviation as well. The **International Civil Aviation Organization** proposed international standards to avoid a patchwork of rules across the globe that often conflict with each other and "hurts us financially and certainly does no good for the environment," according to an industry executive quoted at EurActiv.com. But new technologies are emerging to address these environmental issues. In July, the **Solar Impulse 2 aircraft** completed its 16-month, multistop circumnavigation of the world on solar power to demonstrate the potential for future solar-powered flight. The piloted aircraft spent a cumulative 23 days in flight. According to The Guardian in the U.K., U.N. Secretary-General Ban Ki-moon said: "Solar Impulse has flown more than 40,000 kilometers without fuel, but with an inexhaustible supply of energy and inspiration." ★

***Contributors:** Amir S. Gohardani, Bradley Steinfeldt, Soumyo Dutta, Michelle Rouch*

Accelerating change on systems engineering tenets

BY ERIC E. NICHOLS

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

Virgin Galactic

▲ **Virgin Galactic's** second SpaceShipTwo, the VSS Unity, takes its first flight with its carrier plane Eve over Mojave, California, Sept. 8.

Access to space has been limited by the ticket cost to Earth orbit since the start of the space age. Events over the past year, however, represent what may be a permanent change to the existing cost structure. While deceptively subtle, 2016 saw accelerated changes that affect how we approach two bedrock tenets of systems engineering: requirements management and standards compliance.

System requirements management and design standards matured in tandem with the aerospace industry, often in response to tragic accidents. In the 1920s, airplane construction required little more than advanced carpentry skills. Until the 1930s, rocket technology had changed little since the Congreve rocket used at Fort McHenry in 1814. World War II forced radical change to both technologies.

Integration of ever more complex systems ushered in the nascent field of systems engineering. Reliance on individual experience and intuition was replaced by operational requirements and design standards. The transition helped save countless lives but also created impediments to creative problem-solving; the culture became conservative. Radical new designs became scarce as system specifications began to reflect safe point solutions. The prevalent philosophy became: violate design standards and risk millions of dollars, years of development and loss of life.

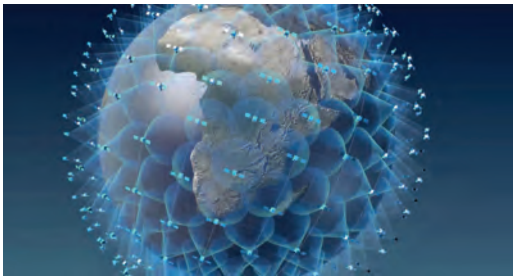
By the 1990s, restrictive standards became the target of government reform. As cost-reduction efforts continued to stagnate, NASA attempted several programs designed to promote innovation and revitalize a commercial space sector. The **Commercial Resupply Service** contracts began the current trend to limited, grand-vision requirements with minimal compliance constraints. The intent was to emulate Air Mail's impact on aviation's early development. These contracts provided the catalyst for SpaceX and Orbital ATK to develop launch vehicles for a commercial market.

The follow-on Commercial Crew Program continued the trend to focus on "what" and not "how." Similarly, the **Ansari "X Prize,"** modeled after early 20th century aviation prizes, promoted maximum creativity with minimal requirements. The simple requirements to launch a reusable crewed vehicle into space twice within two weeks became the inspiration for the space tourism market. Private ventures, including Blue Origin's New Shepard and Virgin Galactic's SpaceShipTwo, use these basic requirements for their suborbital spacecraft and proved there was money available for a purely commercial launch industry.

In 2016 the trend appears to have achieved critical mass with this year's revisions to the **Air Force Evolved Expendable Launch Vehicle**, or EELV, documents. The new directives support the what and not how approach to launch services. With the renewed freedom, launch vehicle designers are once again questioning the existing paradigms and testing cost-saving technologies. The most visible are the reusable systems flown during the year. Less visible are the reduced recurring costs from test and integration changes. The **EELV New Entrant Certification Guide** accommodates providers with innovative designs and higher developmental risk. The guide recognizes possible failure as an integral part of advancing technology. This represents a radical change in launch systems engineering.

Systems engineering developed in response to the need to incorporate complex systems into advanced aerospace designs. System specifications and standards provided the written record used to pass along knowledge and generate design confidence. As the aerospace industry matured, these documents began to drive solutions toward the safe and known and discourage the risky and innovative. The new projects inspiring today's engineers are demonstrating you can have both creative and safe. They are proving the right requirements and appropriate standards can encourage imaginative designs that reduce the ticket cost to Earth orbit.

The challenge for 2017 and beyond is to improve on the successes and work on getting the right mix of requirements and standards. ★



OneWeb

An intriguing year for communications satellites

BY TOM BUTASH

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

▲ **The OneWeb global** internet-delivery constellation will include 720 150-kilogram satellites — 40 in each of 18 low-Earth-orbit planes.

This year may be remembered as one of the most challenging, if not paradoxical years for the communications satellite industry. Despite several satellite communications service operators facing overcapacity, pricing pressures and flat to declining revenues, record amounts of additional capacity will be launched before the second quarter of 2017, and even greater capacity is under development for deployment by the end of the decade. Moreover, an incredible venture capital infusion of $1.8 billion into the industry in 2015 — far more than invested over the prior decade — has enabled "New Space" ventures, including low Earth orbiting, or LEO, and other planned nongeosynchronous orbit broadband constellations, to add even more capacity.

In geosynchronous orbit, Intelsat and NBN Co. each launched additional high throughput satellites, while Hughes Network Systems and ViaSat plan to launch their second-generation high throughput satellites, EchoStar 19 — also known as **Jupiter-2** — and ViaSat-2, late this year and early next year, respectively.

Through mid-September, 11 contracts were awarded for geostationary communications satellites: Four to Space Systems Loral, three each to Boeing and Thales Alenia Space, and one to Lockheed Martin. This award pace suggests 16 satellite awards by the end of 2016, a 33 percent decline from the average of slightly over 24 awards during each of the past four years. The dramatic decline might be attributable to operator sensitivity to near- and intermediate-term challenges, including over-capa city, pricing pressures and flat to declining revenues.

Despite these challenges, many geostationary and large LEO (known as **Mega Big LEO**) high throughput satellite constellations have been proposed and are under development. ViaSat began development of two of three 1-terabit-per-second-capacity geostationary ViaSat-3 satellites for launch by 2020. The capacity of each will be greater than the total capacity of all communications satellites currently on-orbit. Hughes also is planning its third-generation high throughput satellite, Jupiter-3. Motivated perhaps by the International Telecommunication Union's estimate that 3.9 billion people remain unconnected to the internet, Boeing, LeoSat, OneWeb, SpaceX and others have proposed or are developing broadband Mega Big LEO constellations. Several of these are due to go into service by 2020.

The year also saw further progress in reusable rocket technology that might someday lower launch costs by 30 percent or more. In April, SpaceX achieved a first when a Falcon 9 first stage landed on an unmanned barge in the Atlantic Ocean, after boosting a Dragon cargo capsule toward the space station. Previously, SpaceX had only achieved a vertical landing on dry land. Blue Origin demonstrated reusability for the first time in January when the same booster that launched its **New Shepard capsule** to space in November 2015 launched New Shepard again. The European Commission advised the European Space Agency to invest more in reusable technology, citing the American achievements. Ariane 6, under development for first launch in 2020, is unlikely to incorporate reusability before 2030, while the Khrunichev State Research and Production Space Center in Moscow believes its expendable Angara A5 can win 60 percent of the commercial market.

SpaceX's Sept. 1 prelaunch explosion of a Falcon 9 destroyed the Amos-6 satellite and delayed Facebook's plans to provide internet access to sub-Saharan Africa. Prior to the loss, Falcon 9 demonstrated eight launches with six first-stage recoveries.

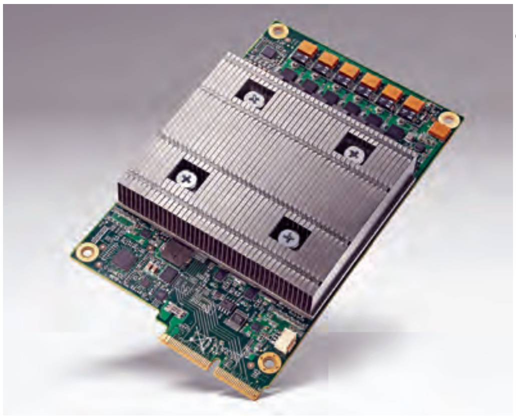
All-electric and hybrid electric-chemical propulsion are becoming the norm, facilitating cost-saving dual launches and greater satellite capacities.

Eutelsat and Space Systems Loral conducted Q/V band transmissions using an experimental payload on **Eutelsat 65 West A**. The companies are assessing the potential of the 40-50 gigahertz band for enabling terabit-per-second high-throughput satellites.

ESA's European Data Relay System-hosted laser communications payload launched on Eutelsat 9B in late January to transmit and receive data at 1.8 gigabits per second.

In June, a United Launch Alliance Atlas 5 launched the U.S. Navy's **Mobile Objective User System-5 satellite**, but MUOS-5's primary orbit-raising system failed before achieving geosynchronous orbit. The Navy began analyzing alternative means of correcting the orbit. ★

Contributors: *Roger Rusch and Joe Pelton*


Google

Google's Tensor Processing Unit board hosts a custom application-specific integrated circuit built for machine learning.

Machine learning, quantum computing speed ahead

BY RICK KWAN

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

China maintained a comfortable lead in high-performance computing. **Sunway TaihuLight**, a supercomputer at China's National Supercomputing Center near Shanghai, was the leader in the June edition of the Top 500 list with 93.0 petaflops. TaihuLight is composed of 10,649,600 computing cores in 40,960 nodes. Designed and manufactured in China, each node is a ShenWei SW26010 chip, with 256 slave compute cores and four management cores, giving a total of 260 cores per chip. TaihuLight displaces the previous champion, Tienhe-2 (Milky Way 2), which performs at 33.9 petaflops, and is built of Intel Xeon processors. In third place is Titan, at Oak Ridge National Lab, running at 17.6 petaflops.

Google's research into machine learning is now integrated in some of its products, including speech recognition, Google Photos, Gmail and search. In late 2015, the company released **"TensorFlow,"** an open source library for software neural networks, thus doing intense numerical computation on clusters of central processing units and graphics processing units. In May, Google announced a hardware enhancement. The Tensor Processing Unit, or TPU, is a custom chip built for machine learning — particularly for TensorFlow. TPUs had been at work in Google's data centers for over a year and were giving an order of magnitude better performance per watt for machine learning than GPUs, not to mention CPUs.

For a wide range of optimization problems, quantum computing may prove even faster. Google, NASA's Ames Research Center in California and Universities Space Research Association, based in Washington, D.C., are cooperating in the Quantum Artificial Intelligence Laboratory at Ames. The QuAIL project has a D-Wave 2X, with more than 1,000 quantum bits. In a paper published in January, Google researchers reported quantum annealing that ran many orders of magnitude faster than simulated annealing on a conventional single core machine.

The Juno spacecraft entered a highly elliptical orbit around Jupiter on July 4 and will make multiple passes through Jupiter's radiation belts. The mission design prompted the construction of an "electronics vault," essentially a titanium box, to shield the avionics, including its BAE Systems RAD750 computer, from the more extreme effects of the radiation.

The mobile processors found in devices like smartphones and tablets are fueling competition for mass market consumption of small unmanned aircraft. DJI, of Shenzhen, China, released an embedded computer based on Nvidia's Tegra TK1 as a developer platform for its popular line of camera-carrying drones in November last year. In January, Intel announced it had acquired German drone maker Ascending Technologies. At the Consumer Electronics Show that month, the company showed a video of "Drone 100," a swarm of 100 drones performing an airborne music and light show. The drones gave a live performance in June at Australia's Sydney Opera House and were accompanied by the Sydney Youth Orchestra.

NASA's Goddard Space Flight Center in Maryland issued a request for proposal in June for the **High Performance Spaceflight Computing Processor Chiplet project**. It aims to develop a next-generation, radiation-hardened, general-purpose, multicore processor for use by NASA and the U.S. Air Force for crewed and uncrewed spacecraft. As currently envisioned, the four-year project would deliver a quad-core, radiation-hardened version of the ARM Cortex-A53, including the single-instruction, multiple-data Neon extension.

Meanwhile, BAE has received the first silicon for its RAD5545 system on a chip, a quad-core implementation of the **RAD5500 32/64-bit Power Architecture**. It has over 19 times the performance of the RAD750 on Juno. Maximum processor throughput is 5.6 billion operations per second or 3.7 billion floating point operations per second. It is built using a radiation-hardened-by-design circuit library using a 45-nanometer silicon-on-insulator fabrication process. It is designed to work with the SpaceVPX standard, supporting RapidIO and SpaceWire hardware protocols. ★

Contributor: *Joe Marshall*

NASA

Progress on avoidance, guidance and displays

BY ERIK THEUNISSEN

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

▲ **The modified dome** on NASA's Ikhana unmanned aircraft system, foreground, houses the General Atomics-designed detect-and-avoid radar. The Honeywell King Air in the background served as an intruder during detect-and-avoid flight tests.

On the long road to allowing unmanned aircraft full access to the National Airspace System, 2016 was a pivotal year for achieving important milestones in the area of sensors, algorithms, displays, flight testing and development of the minimum operational performance standards.

For unmanned aircraft to meet the intent of the **International Civil Aviation Organization's Annex 2**, a technical solution is being developed to enable a detect-and-avoid, or DAA, capability. RTCA's **Special Committee 228**, or RTCA SC-228, is developing a technical standard for airborne and ground-based equipment that will aid remote pilots in remaining well clear of and avoid collisions with other airspace users. Using a variety of sensors, such DAA equipment will detect cooperative as well as noncooperative intruder aircraft and provide pilots with aural and visual guidance for remaining well clear. One of the key features of the "Phase I" system SC-228 is codifying the alerting and guidance that the remote pilot will receive to avoid a future loss of "well clear."

In anticipation of future alerting, guidance and display requirements for DAA, General Atomics Aeronautical Systems started the development of the Conflict Prediction and Display System in 2009. The guidance functionality embedded in CPDS is based on the mathematical foundation developed by researchers at NASA's Langley Research Center in Virginia for conflict prevention algorithms. Initially, many CPDS design requirements followed from RTCA DO-317B, but the community was still working on agreement of key aspects, such as the definition of **"well clear."** As the minimum operational performance standards matured during 2015 and 2016, CPDS was updated in terms of alerting and guidance functions and display. Questions on draft alerting and guidance criteria related to minimum operational performance standards have been addressed, in part, using flight tests.

A key question for alerting and guidance concerns the interoperability with the existing traffic collision avoidance system, or TCAS. To address this question, dedicated multi-intruder conflict geometries have been designed that are aimed at triggering both DAA and TCAS alerts, as well as encounters that should only trigger DAA alerts. Initial analysis was performed using simulations to gather baseline data. An important milestone in 2016 was the gathering of data for such encounters during actual flight. The data was collected as part of the NASA-led series of flight tests known as **"Flight Test 4."** These DAA system flight tests included collaborative contributions from the FAA, NASA, Honeywell, General Atomics and BAE Systems. The prototype DAA system used in these flight tests included a surveillance suite comprised of a TCAS providing active transponder-based surveillance, a transponder capable of ADSB-In and a General Atomics-designed air-to-air radar for DAA.

A Honeywell-developed surveillance algorithm produces a single track onboard the aircraft, which is then downlinked to the ground control station using satellite communications. NASA's **Ikhana unmanned aircraft system** has been used as the primary test vehicle, and several Honeywell and NASA aircraft have been intruders. Using encounter geometries with up to four closely spaced intruders, the capability of the new DAA radar to distinguish between different tracks on a timely basis was demonstrated in June 2016.

A key capability for the 2016 flight tests was a real-time view of the behavior of the DAA alerting parameters, which significantly contributed to determining whether an encounter had been executed accurately.

The DAA minimum operational performance standards are in their final phase of development and were to be published by the end of the year. Meanwhile, the CPDS has been extended to be compatible with the latest version of the FAA's Airborne Collision Avoidance System for Unmanned Aircraft to begin to address "Phase II" capabilities within RTCA SC-228 and SC-147. ★

Contributor: *Brandon Suarez*

AI system defeats expert human pilot

BY ELAD KIVELEVITCH

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

Following three years of work led by the Intelligent Systems Technical Committee, the first edition of the Roadmap for Intelligent Systems in Aerospace was released. The recommendations are anticipated to catapult the aerospace industry to new levels of safety, performance, efficiency, capability, resilience and autonomy. The committee anticipates that by following the recommendations, the U.S. will maintain its leadership in the aerospace domain.

During 2016, research and development in intelligent aerospace systems has produced notable advancements that led to a higher level of auto nomy, performance, resilience, robustness and safety, both at the platform level and between platforms.

Iowa State University, with NASA and Fondazione Bruno Kessler of Italy, is scaling up capabilities for early design-stage analysis of automated air traffic control. The initial design space had over 20,000 possibilities for the **NextGen air traffic control architecture**. Aircraft could be separated by ground control, be self-separating or switch between the two — with differing options for burdening rules and inter-aircraft communication. Analysis of the safety and robustness to failure of partial designs enables efficient narrowing of the design space, saving time and cost. The team combined model checking with contract-based design, creating a fully automatic approach to generate large numbers of models and validate all target designs.

The German Aerospace Center, or DLR, is working on a framework for run-time monitoring of complex formal specifications, based on a tool for the stream-based specification language LOLA, currently developed at Saarland University in Germany. The benefits of utilizing the concept of run-time monitoring are currently experienced firsthand, while integrating the DLR **Autonomous Rotorcraft Testbed for Intelligent Systems**, or ARTIS, software framework to a new research vehicle, SuperARTIS, a 85-kilogram maximum-takeoff-weight helicopter based on SDO 50 V2 from SwissDrones Operating AG of Switzerland.

In a ground-breaking development, an artificial intelligence system developed by Ohio-based Psibernetix defeated a human expert pilot in simulated air-to-air combat conducted in the Advanced Framework for Simulation, Integration and Modeling high-fidelity simulation environment for the U.S. Air Force Research Laboratory. Using the genetic fuzzy tree methodology, Psibernetix's Alpha defeated other AI and multiple human opponents, even when disadvantaged with respect to aircraft and payload capabilities. Retired U.S. Air Force Col. Gene Lee described Alpha as "the most aggressive, responsive, dynamic and credible AI [he's] seen to date."

The **Automatic Ground Collision Avoidance System** is an intelligent aerospace system designed to prevent imminent ground collisions caused by pilot-controlled flight into terrain, spatial disorientation and G-force-induced loss of consciousness. The system compares a projected recovery trajectory with an onboard digital terrain elevation data map and commands a recovery maneuver after an aware pilot would have already recovered. Since fielding on U.S. Air Force block 40/50 F-16s, the system has four confirmed saves during basic fighter maneuver training.

Information security can be the weakest point in any interconnected intelligent system. The Trustworthy Data Engineering Laboratory at the University of Cincinnati developed techniques for secure publish-and-subscribe capabilities of mission and operational data as part of the NASA Seedling Project's **Efficient Reconfigurable Cockpit concept**. The lab developed an architecture able to maintain mission-critical functions during failure and when under attack. The architecture consists of a trusted hardware layer composed of intelligent hard points that allow sensors and other physical components to be directly integrated and authenticated into the secure environment and novel algorithms for privacy-enabled searchable encryption mechanisms. Together, these components allow secure communication of data, commands and inter-aircraft communication, turning our airspace into a single, secure, distributed computer. ★

▼ **DLR's Autonomous** Rotorcraft Testbed for Intelligent Systems serves as a technology demonstrator and research platform.

DLR

Electric efforts gaining power

BY JOHN NAIRUS

The **Energy Optimized Aircraft and Equipment Systems Program Committee** focuses on increasing electric power and implementing thermal management technologies for efficient, more capable green aircraft.

NASA

▲ **The NASA Electric Aircraft Testbed** in Sandusky, Ohio, is the first reconfigurable hybrid gas-electric propulsion test bed intended for full-scale single-aisle electrified aircraft powertrain development.

Much has happened in 2016 as electric aircraft development has really taken off for commercial applications and as the military continues its more-electric development.

The U.S. Air Force's **Integrated Vehicle Energy Technology**, or INVENT, program is in its final year with the integrated ground demonstration scheduled to be completed in fiscal 2017. INVENT has been focused on working aircraft electrical power and thermal management applicable to both current and future aircraft. As INVENT winds down, the Air Force has also embarked on advancing **MegaWatt Tactical Aircraft**, or MWTA, which shares similar technology challenges with NASA's hybrid-electric propulsion initiative. NASA and the Air Force have also kicked off a joint effort to extract megawatt-class electrical power from a single propulsion engine. The service is also wrapping up construction on its megawatt power and thermal integration facility at Wright-Patterson Air Force Base, Ohio, and begun installing facility infrastructure for an in-house resident capability at the same location to complement INVENT and MWTA efforts with industry. During construction, a 5-foot wind tunnel commissioned by one of the Wright brothers a century ago was repurposed.

The **NASA Electric Aircraft Testbed** facility repurposes a NASA asset originally designed for nuclear thermal propulsion testing to accommodate current and future research needs for electrified aircraft propulsion. The facility is the first reconfigurable hybrid gas-electric propulsion test bed intended for full-scale single-aisle electrified aircraft powertrain development. It has infrastructure for up to 12 megawatts of input power — 48 if regenerated — remote control of operations, support for cryogenic fuels and multimegawatt cooling capacity.

The facility, located near Sandusky, Ohio, completed its first aircraft engine emulation test suite in the summer. The emulated flight profile included actual takeoff, climb and cruise conditions for a scaled CF34 turbofan including inertia, N1, and torque loading with 20 millisecond transient fidelity. In addition to demonstrating high fidelity ducted fan transient emulation, future experiments will establish baseline power quality, electromagnetic interference levels, and validate aircraft powertrain modeling predictions.

Electronic materials development is crucial to the improvement across these industries. In 2016 the **Interagency Advanced Power Group** continued to serve as a forum for more detailed discussion and information sharing in the materials associated with electric and electronic circuitry, devices, current flow, control and conversion. The rapid introduction of new wideband gap devices made from silicon carbide and gallium arsenide is changing the landscape of efficient power component design by increasing operational temperature, voltage and frequency ranges. As semiconductor devices improve, focus is expanding to other materials such as the soft magnetic materials central to filtering and power conversion. These materials are being applied to component prototypes for NASA, Defense Department and Department of Energy-funded power electronics.

The Institute of Electrical and Electronics Engineers and the Grainger Center for Electrical Machines and Electromechanics sponsored a special workshop **"Technology Roadmap for Large Electrical Machines"** in April at the University of Illinois Urbana-Champaign. The intent of the workshop was to bring together leading researchers, thought leaders, application experts and key stakeholders across the industry, academia and government to generate a consensus-based roadmap for transformational technologies for emerging applications such as subsea oil and gas processing, offshore wind turbines and electric aircraft.

The workshop participants chose electrified aircraft as their focus technology and are seeking further synergy between traditional IEEE and traditional AIAA stakeholders. ★

Contributors: *Cheryl Bowman; Elena Garcia*

Going green moves to higher gear

BY GARY A. DALE

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

Lockheed Martin

Tests at the Lockheed Martin Low Speed Wind Tunnel in Ohio confirmed the low-speed handling qualities of the Hybrid Wing Body, which is targeted to use 51 to 74 percent less fuel over today's commercial freight missions.

Environmental regulations will increasingly impact future aviation, as witnessed by events in 2016. In February, following six years of development, the **International Civil Aviation Organization**, or ICAO, took a significant step on efficiency targets with an agreement on CO_2 emissions standard. If adopted by ICAO's governing council, then the Committee on Aviation Environmental Protection will impose the first-ever binding energy efficiency and CO_2 reduction targets for aviation.

In July the U.S. Environmental Protection Agency finalized a determination that greenhouse gas emissions from certain types of aircraft engines contribute to the pollution that causes climate change and endangers health.

NASA completed its six-year **Environmentally Responsible Aviation** project that aims to reduce aviation's environmental impact. Partnering with U.S. industry and other government agencies, researchers matured advanced commercial transport technologies that reduced aircraft drag, weight and noise, as well as reduced the fuel burn and oxides of nitrogen output of the engines. If applied to the U.S. fleet starting in 2025, NASA's analysis shows the technologies could help U.S. airlines realize over $250 billion dollars in savings from 2025 to 2050, and claim large reductions in carbon and noise footprints.

NASA in September awarded contracts to Aurora Flight Sciences and DZYNE Technologies, both in Virginia, along with Boeing and Lockheed Martin for system requirements definitions for promising X-plane concepts. The contracts support NASA's 10-year **New Aviation Horizons** initiative to further develop technology with U. S. industry and other government partners to enable revolutionary ultra-efficient subsonic transport aircraft. Objectives are the simultaneous reduction of fleet-level carbon footprint of aviation by at least 50 percent and reduction of perceived community noise levels by one-half, while significantly reducing landing and takeoff emissions.

The European community is also addressing environmental and economic performance targets. **Clean Sky 2** is focused on integrating breakthrough technologies at aircraft level and delivering in-flight demonstration of novel architectures and configurations. One example is the BLADE, or **Breakthrough Laminar Aircraft Demonstrator in Europe**, flight demonstrator: its A340 with new natural laminar flow on the outer wings. The wing assembly is nearing completion at Aernnova in Spain.

In Japan the **National Institute for Materials Science** has achieved energy conversion efficiency exceeding 18 percent using standard size perovskite solar cells, a key driving technology toward the government's goal of doubling conversion efficiency and lowering power generation costs.

In June, Solar Impulse completed the first circumnavigation of the globe, flying 40,000 kilometers without fuel to promote the use of renewable energies. Airbus Group confirmed production plans for its electric aircraft **E-Fan 2.0**. Initial production volume will be small, but could grow to some 80 units annually by 2025, according to the company.

The White House in July released its strategy for setting out prioritized research and development goals to address key scientific and technical challenges holding back the development, production and use of economically viable alternative jet fuels at commercial scale. The FAA continued its five-year effort under the **Continuous Lower Energy, Emissions and Noise Program** to develop and demonstrate certifiable aircraft technologies to reduce aircraft fuel burn, emissions and noise, as well as to advance the development and introduction of sustainable alternative jet fuels. Recently, a new alternative — environmentally friendly, bio-based jet fuel, alcohol to jet synthetic paraffinic kerosene — was approved by ASTM International of Pennsylvania.

In March, United Airlines launched an initiative that uses biofuel to help power flights running between Los Angeles and San Francisco, with eventual plans to expand to all flights operating out of Los Angeles International. It's the first time an American airline is using renewable fuel for regular commercial operations. ★

Hypersonics changing the world

BY KEVIN KREMEYER

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

In the global hypersonic renaissance, nations around the world are developing and demonstrating increasingly impressive capabilities to reduce travel time. The most dramatic demonstrations have come from China and Russia, with China demonstrating extreme maneuvers between Mach 5-10 on its **DF-ZF gliding flight vehicle**, during the platform's seventh flight test in April. China has hundreds of hypersonic wind tunnels that enable rapid development of its hypersonic platforms.

Concurrently, Russia is focusing on marketable products for space launch and missiles. Its aggressive timeline to generate return on investment is demonstrated by the intention to bring both its **RS-28 Sarmat Intercontinental Ballistic Missile** (capable of a 10-ton payload) and the **Zircon Hypersonic** (Mach 6) **Cruise Missile** into production in 2018. Also in April, Russia completed the second publicized flight test of its Yu-74 hypersonic (Mach 10) glide vehicle, which was released by a ballistic missile, and maneuvered over long range to hit a target. The test indicated the ability to hit a target within a 6,200-mile (10,000-kilometer) radius in under an hour, and guided final design aspects.

Russia also played an integral role in India's **Hypersonic Technology Demonstrator Vehicle** (HSTDV) to attain autonomous scramjet flight, as India develops reusable launch vehicles and BrahMos Aerospace's family of hypersonic missiles, an Indian/Russian joint venture. Israel provided wind tunnel testing for the HSTDV program, as did Cranfield University in the U.K. France is also working with Russia's Raduga and Rosoboronoexport, to develop a Mach 4-8 missile.

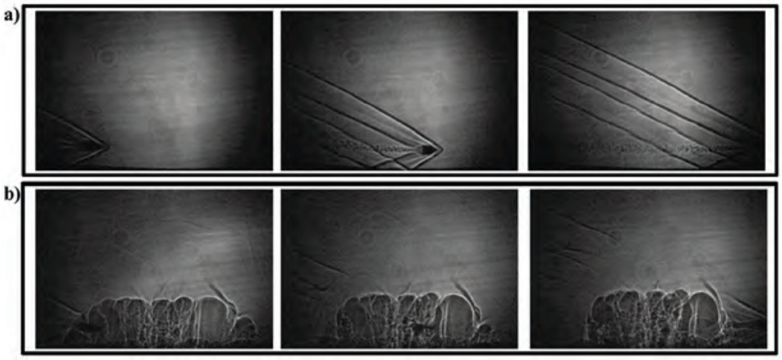
The Brazilian Space Agency was invited to participate in the European, Russian and Australian Hexafly International consortium, while in May Australia's Defence Science and Technology Group conducted the Mach 7.5 experiment 5B flight test under the **Hypersonic International Flight Research Experimentation** program, involving researchers from the University of Queensland, the U.S. Air Force Research Laboratory and Boeing to obtain boundary layer transition data.

AFRL has also taken initial steps on its HyRAX reusable hypersonic test bed vehicle program, working with DARPA, contracting primarily with Lockheed and Raytheon and their contractors on the Tactical Boost Glide and Hypersonic Air-breathing Weapon Concept demonstration programs, to mature technologies, increase confidence and reduce risk. Both programs have completed their preliminary designs.

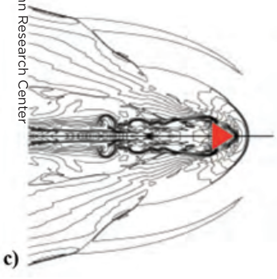
To mature and transition key technologies, systems and operational processes to the military and commercial sectors, DARPA is further pursuing its **Experimental Spaceplane**, or XS-1, program to fabricate and fly a reusable aircraft to the edge of space. The program has completed preliminary design and is poised to enter phases 2 and 3 for fabrication and flight test.

To address this renewed interest, inactive test facilities are coming online, as are new hypersonic wind-tunnels and shock/Ludwieg-tubes, and upgrades are being implemented across the U.S. These developments are taking place at NASA, military and national laboratories, along with more than a dozen universities, with the University of Texas at Arlington installing the first U.S. university-based, arc-heated, hypersonic-testing facility for thermal protection systems.

PM&AM Research performed range and wind tunnel tests to validate simulations, including highly efficient surface-drag reduction and elimination of shock waves, commensurate with dramatic improvement in speed, maneuverability, heating, drag, sonic boom and efficiency. The high efficiencies increased with Mach number, and the effects promise dramatic advances in performance that are otherwise impossible to achieve, thereby standing to revolutionize supersonic and hypersonic travel. ★



NASA Glenn Research Center

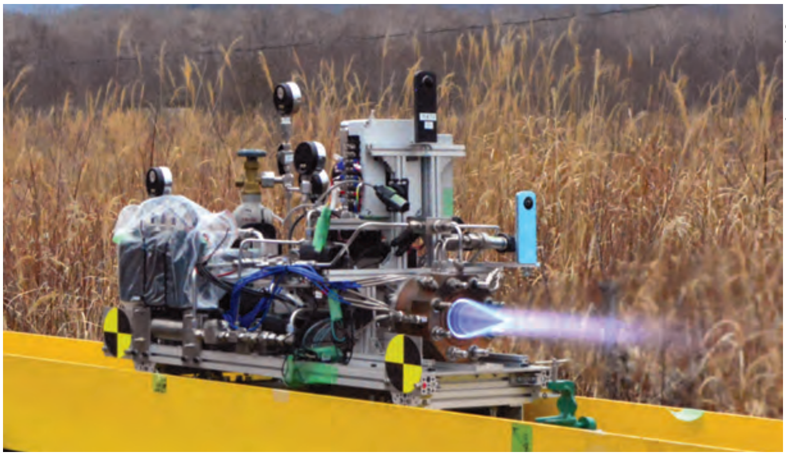


The shadowgraph in image a) shows density contours of a shock structure when propagating through quiescent air. **Image b)** shows shock structure when propagating through a low-density region. **Image c)** shows a simulation predicting the same elimination of shock structure when passing through a similar upstream low-density region.

New and existing systems show progress

BY SCOTT CLAFLIN

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



Nagoya University

▲ **A rotating detonating engine developed in Japan** is being used to evaluate engine thrust and confirm stable operation under vehicle acceleration.

The state of the art in pressure gain combustion advanced significantly this year as numerous government, industry and academic institutions continued to develop new experimental engines and mature analytical models.

In the U.S., both the Defense Department and the Department of Energy are supporting PGC development. Under an Office of Naval Research grant, the Naval Postgraduate School in Monterey, California, explored the impact of engine inlet characteristics on the delivered performance of a **rotating detonation engine**, or RDE. The investigation involved hot-fire testing with detonation zone imaging, optical diagnostics and collaborative computation efforts with the Naval Research Laboratory, NRL, in Washington, D.C. The Naval Postgraduate School also supported a DARPA-funded team comprising HyPerComp Inc. of California, the University of Connecticut and Aerojet Rocketdyne of California in developing a **continuous detonation turbine engine**. The program measured turbine efficiency when driven by the unsteady flow of an RDE.

Under National Energy Technology Laboratory, or NETL, sponsorship, the University of Michigan, Penn State University and Purdue University have begun RDE development on the University Turbine Systems Research Initiative. In September, NETL awarded a three-year phase 2 program to **Aerojet Rocketdyne** to advance air and natural gas RDE technology.

NETL continued its own internal research that includes fundamental bench-scale experiments, lab-scale experiments and computational studies. The bench-scale rig is evaluating RDE fuel and air inlet geometries. The 6-inch lab-scale RDE with ducted exhaust has been tested with variable back pressure control permitting operation at elevated pressures. The rig is currently being modified to permit oxides of nitrogen emissions measurements.

The **Air Force Research Laboratory** is collaborating with NETL on the testing of an RDE combustor coupled to a T63 gas turbine engine. These tests are evaluating RDE-to-turbine interface conditions and potential impact on turbine performance as well as oxides of nitrogen emissions. At NRL, recent numerical simulations of an air/hydrogen RDE using detailed chemistry show that those emissions can be kept to an acceptable level by suitably choosing the equivalence ratio and engine geometry.

The NASA Glenn Research Center in Cleveland continued PGC investigations by demonstrating performance improvements through simulation of a resonant pulse combustor concept. Also, RDE modeling, validation and optimization capability expanded via collaboration with the Air Force Research Laboratory.

Academia made significant progress in PGC development this year. A team from the University of Washington demonstrated success in controlling the spin direction of an **RDE detonation wave** using a system that emits circumferentially phased sequential sparking. Purdue is working on an effort sponsored by the Air Force Office on Scientific Research that focuses on combustion characteristics in high-pressure rocket RDE devices. Three successful test series have been undertaken: two with gaseous hydrogen and one with natural gas fuels. A NASA and Purdue-sponsored effort in pulse detonation engines, PDEs, completed the final round of testing in which natural valveless detonative performance was achieved using high concentration hydrogen peroxide with hypergolic fuels in a nozzleless combustor.

Research on both RDE and PDE technology is robust outside of the U.S. A Japanese research group from Nagoya University, Keio University, JAXA and Muroran Institute of Technology conducted a successful sled test of an RDE, and the group has started development of an RDE-powered sounding rocket. In Russia, the Semenov Institute of Chemical Physics successfully operated an RDE with air and liquid propane by augmenting the detonation process with hydrogen. In Saudi Arabia, the King Abdullah University of Science and Technology has developed and characterized a novel, actively valved and acoustically resonant pulse combustor with pulsed fuel injection. The pulsed combustor is designed to produce meaningful pressure gain with low pollutant emission in a gas turbine engine. ★

Orbital ATK

Space Launch System keeps pace for 2018 liftoff

BY BRIAN O'CONNOR

The **Space Environmental Systems Program Committee** focuses on environmental and thermal control technologies for aircraft, spacecraft and space missions.

▲ **An Orbital ATK technician inspects hardware** and instrumentation on a full-scale test version of NASA's Space Launch System launch vehicle. Tests include the effects of temperature on how the propellant burns.

NASA's **Space Launch System**, or SLS, continued development toward a November 2018 launch date of the Block 1 (70-metric ton lift) vehicle, and has begun development of the Block 1B (105-metric ton lift). In June, the Qualification Motor 2 test firing was completed at Orbital ATK's Promontory Propulsion Systems facility in northern Utah. The motor was a full-scale five-segment Solid Rocket Booster that will be used for SLS. By cooling the motor for more than a month using large air-conditioning units, this test was conducted at the minimum propellant temperature of 40 degrees Fahrenheit. When ignited, those temperatures inside the booster reach nearly 6,000 degrees Fahrenheit.

The **Marshall Space Flight Center** in Huntsville, Alabama, continued development of more environmentally friendly cryogenic insulation materials for use on the Block 1 Core Stage and Block 1B Upper Stage cryogenic tanks. Testing of the foam systems will be conducted by NASA and prime contractor Boeing to qualify the insulation for the challenging environments SLS will experience before and during flight. Marshall has tested conceptual designs to protect the Core Stage flight base heat shield thermal protection system during the "Green Run" static test firing. The designs involved spray-on foam insulations that could be removed after testing, as well as surface coatings to reduce the plume radiation heat loading on the heat shield. Additionally, several characterization development tests of various cryogenic areas of the vehicle that could form ice and frost have been performed. Ice and frost could lead to both additional vehicle mass and a potential debris source that could lead to dangerous impact damage during ascent.

GOES-R, the first of four, planned next-generation **Geostationary Operational Environmental Satellites**, completed environmental testing at Lockheed Martin Space Systems in Denver earlier this year and was flown to Florida aboard a massive U.S. Air Force C-5M Super Galaxy cargo plane. There, it arrived at the Astrotech Space Operations facility in Titusville outside Kennedy Space Center for final assembly, including thermal blanket installation, electrical testing and fueling. GOES-R will provide faster weather coverage, better data for severe weather forecasts, advanced warning of space weather hazards, and improved transportation safety. The mission operations team conducted the final mission rehearsal in September from the NOAA Satellite Operations Facility in Suitland, Maryland. The satellite was scheduled to launch aboard an Atlas V 541 at Cape Canaveral in late November to begin its 15-year mission.

The thermal design for the **Iodine Satellite** has progressed leading up to critical design review. The 12-unit cubesat system has unique thermal considerations with an iodine propellant that requires specific temperature profiles throughout the feed system to sublimate the propellant at specific flow rates, while mitigating deposition along the flow path. The spacecraft thermal design is compartmentalized and will demonstrate a power density an order of magnitude higher than state-of-the-art smallsats. The thermal design utilizes both custom heaters and insulation; it also may rely on attitude control during operation to maintain appropriate temperatures. NASA's Glenn Research Center in Cleveland is leading the propulsion thermal design and Marshall is leading the integrated bus solution. ★

Mars, Jupiter and the human factor

BY CHRIS MOORE AND SURENDRA SHARMA

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

NASA's Juno spacecraft entered Jupiter's orbit on July 4 after a journey of almost five years. Juno will orbit Jupiter 37 times to investigate the composition and structure of the deep atmosphere, to map the planet's magnetic and gravitational fields, and to study the auroras. The spacecraft has taken the first pictures of Jupiter's North Pole.

The **Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer**, better known as OSIRIS-REx, asteroid sample return mission was launched on Sept. 8. The spacecraft will rendezvous with the near-Earth asteroid Bennu, collect a sample of surface material with its robotic arm and return the sample to Earth via a detachable capsule in 2023. Bennu is a carbon-rich asteroid that may contain organic molecules, volatiles and amino acids that may have been the precursors to life on Earth.

After an extensive review process, NASA is ready to proceed with the final design and construction of the **Mars 2020 rover**. The rover will investigate a region of Mars where the ancient environment may have been favorable for microbial life. It will collect samples of soil and rock and cache them on the surface for possible return to Earth by a future mission. To reduce risk and cost, the 2020 rover will look much like its six-wheeled predecessor, Curiosity, but with an array of new science instruments to explore Mars as never before. The rover will also conduct the first demonstration of oxygen production from the Martian atmosphere in preparation for human missions.

Astronomers at the European Southern Observatory in Chile announced they had discovered a planet slightly larger than Earth orbiting in the habitable zone of the nearest star, **Proxima Centauri**, which is 4.3 light years distant from our solar system.

In human space exploration, American astronaut Scott Kelly and Russian cosmonaut Mikhail Kornienko returned to Earth on March 2 after a historic 340-day mission aboard the International Space Station. Their mission investigated the medical and psychological effects of long-duration spaceflight on the crew's health and performance. The knowledge gained from this mission will help NASA develop plans for sending humans to Mars on missions lasting over 1,000 days.

There are many signs of progress as NASA works toward the first launch of the Space Launch System, or SLS, in 2018. In June, a second qualification firing of the solid rocket booster was conducted at Orbital ATK in Utah. In July, a 650-second test of an RS-25 engine for the core stage was conducted at Stennis Space Center, Mississippi. NASA completed fabrication of a qualification test article for the 130-foot-long SLS liquid hydrogen tank at the **Michoud Assembly Facility**, New Orleans. Construction of a structural test stand for the core stage has been completed at Marshall Space Flight Center, Alabama. New work platforms are also being installed in the Vehicle Assembly Building at Kennedy Space Center, Florida, where SLS will be assembled.

In space exploration technology, the **Bigelow Expandable Activity Module**, or BEAM, was successfully deployed on the ISS. The objective of BEAM's 2-year mission is to demonstrate human-rated inflatable structures technology for a deep space habitat. BEAM is instrumented with sensors to characterize its structural integrity and internal radiation environment. NASA is planning to test a habitat in the proving ground of cislunar space in the mid-2020s before sending humans to Mars.

In August, NASA awarded public-private partnerships to six companies — Bigelow Aerospace, Boeing, Lockheed Martin, Orbital ATK, NanoRacks and Sierra Nevada — to develop prototype cislunar habitats for ground testing in 2018. The companies are contributing 30 percent of the funds to the partnerships and plan to leverage the same technologies for developing commercial habitats in low Earth orbit. ★


NASA

◀ **The 130-foot-long fuel tank test article** for NASA's Space Launch System launch vehicle is removed from the Vertical Assembly Center at Michoud Assembly Facility in New Orleans in July after welding.

Facebook

Unmanned integration efforts gain speed

BY RICHARD S. STANSBURY

The **Unmanned Systems Program Committee** supports the unmanned systems community focused primarily on unmanned aircraft systems and related technologies, but also supports ground, sea and space-based unmanned systems technical communities.

▲ **The solar-powered Aquila** high-altitude unmanned aircraft flew in July. Facebook hopes eventually to use it to bring the internet to people in remote areas.

The unmanned aircraft systems community made tremendous strides toward its goal of UAS integration in 2016, with a huge effort going into connecting the UAS community with policy- and rule-makers.

In April, the FAA held a UAS symposium in Daytona Beach, Florida, to discuss UAS integration into the National Airspace System. In May, FAA Administrator Michael Huerta announced the formation of a **Drone Advisory Committee**, comprised of members from industry, government and academia, to open a dialog between rule-makers and the community. The panel held its inaugural meeting in September.

On Aug. 2, the White House Office of Science and Technology Policy held a workshop on **"Drones and the Future of Aviation"** where it pledged further support to UAS integration efforts that included funding to the National Science Foundation, support for search-and-rescue operations using UAS by the Department of Interior, $5 million to support UAS development in New York state, and support for public and UAS community outreach.

The FAA made further regulatory progress in 2016. An aviation rule-making committee was convened to develop initial guidance regarding the operation of micro-unmanned systems over populated areas. Its final report was delivered to the FAA on April 1. In June, the FAA announced the final rules for Title 14 Code of Federal Regulations Part 107, Operation and Certification of Small Unmanned Aircraft Systems, which went into effect Aug. 29. Part 107 defines operational restrictions for small UAS operator certification requirements for a new remote pilot certificate with small UAS rating, and a waiver process to request exemptions for some Part 107 restrictions given appropriate risk mitigations.

NASA's UAS Traffic Management system and associated research program achieved several milestones in 2016. In April, a test was performed in partnership with the FAA's six UAS test sites in which 24 UAS flights operated under the traffic management system across the multiple sites with up to 22 simultaneous flights. In August, at the Reno-Stead Airport UAS test site in Nevada, NASA performed the first checkout of the traffic management system for Technology Capability Level-2, in which basic principles of air traffic management for low-altitude small UAS operations have been analyzed and some preliminary application of that knowledge has been achieved.

The Defense Department also addressed the path forward for autonomy across their unmanned systems as reported in the Defense Science Board's **"Summer Study on Autonomy."**

A major public concern of UAS technologies is operations outside the current legal framework. In March, the FAA released a report on UAS reported sightings, which included 582 reported encounters by pilots, citizens and law enforcement from Aug. 21, 2015, to Jan. 31, 2016. The FAA expanded its **Pathfinder Initiative for UAS detection** by issuing Cooperative Research and Development Agreements to Gryphon Sensors of New York, Liteeye Systems of Arizona and Sensofusion to evaluate their technologies for UAS detection. The FAA also field tested an FBI-provided mitigation system at John F. Kennedy International Airport versus a variety of UAS platforms.

UAS have also made the news for a variety of positive applications that included these examples. In July, Facebook announced the first full-scale flight test of the **Aquila solar-powered high-altitude UAS platform**, which is designed to one day provide internet access to remote areas. In July, over 250 unmanned aircraft flights were performed as part of the National Science Foundation's Cloud-Map project evaluating UAS for applications in precision agriculture and meteorology by a team of universities including. Universities taking part included the University of Kentucky, the University of Oklahoma, Oklahoma State University, and the University of Nebraska. In August, Stony Brook University in New York and Vayu Inc. in Michigan performed the first flight test to transport blood samples from a remote village in Madagascar to a field medical station, paving the way to faster diagnosis for people in remote villages. ★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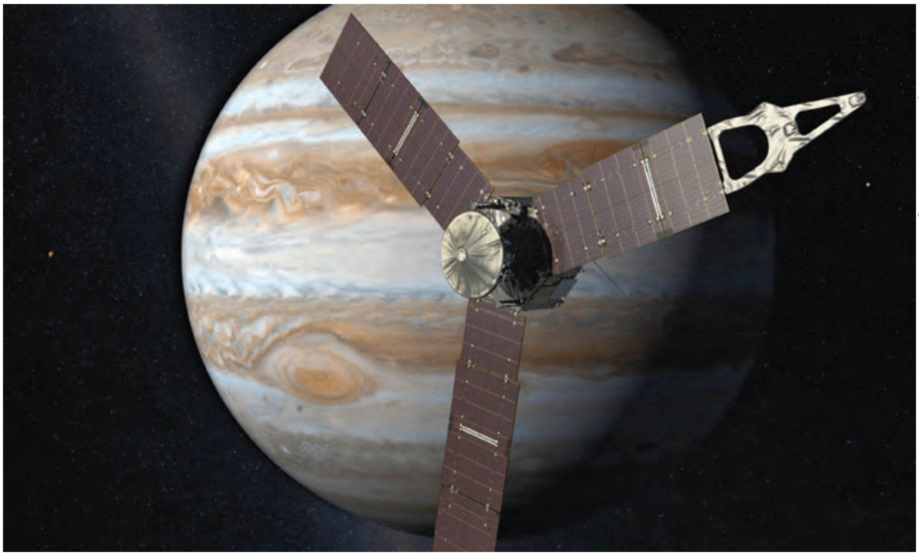


NASA/Jet Propulsion Laboratory-CalTech

▲ **The Juno spacecraft,** shown in an artist's rendering, began orbiting Jupiter in July.

Solar power stars in Juno misson; nuclear work progresses

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.

The **Juno spacecraft** arrived in orbit around Jupiter on July 4 after a five-year journey. The mission is part of NASA's New Frontiers Program and is managed by NASA's Jet Propulsion Laboratory for the principal investigator, Scott Bolton, of Southwest Research Institute in San Antonio.

In January, Juno became the most distant solar-powered spacecraft and has now completed the first of 36 orbital flybys of Jupiter, sending back the first images ever of Jupiter's North Pole and the first infrared images of its South Pole.

The solar arrays are performing as predicted in this low-intensity sunlight, low-temperature environment. As opposed to the Galileo mission, whose power system was not affected by the radiation belts, Juno adjusted its orbit to reduce the radiation impact on the solar arrays by following a polar elliptical orbit outside of the radiation belts and going in for short-duration flybys. The solar array performance is closely monitored to help inform future deep-space solar missions.

NASA's **Radioisotope Power Systems** program, led by JPL, is transferring to industry partners new thermoelectric energy conversion technologies that use skutterudite thermocouples. The target application would be a one-for-one substitution of the couples in the flight-proven Multi-Mission Radioisotope Thermoelectric Generator, with the potential to enhance its power output by 50 percent at the end of a 14-year mission application. The program also has initiated a procurement for prototype candidate converters demonstrating efficient dynamic power conversion. In addition to investments in energy conversion technologies, the program, in partnership with the U.S. Department of Energy, restarted production of the heat-source material.

Production capabilities of plutonium dioxide continued to be scaled upward this year toward a goal of 1.5 kilograms per year, after the **Plutonium-238 Supply Project**, led by the Energy Department's Oak Ridge National Laboratory in Tennessee, achieved a long-awaited milestone by producing a 50-gram sample of Pu-238. It was the first new Radioisotope Power System fuel produced in the United States in nearly 30 years.

Preliminary testing of the **Kilopower nuclear technology demonstration assembly** using an electrically heated stainless steel reactor core simulator was conducted at NASA's Glenn Research Center near Cleveland. This demonstration of a small fission reactor power system is focused on space missions needing 1-10 kilowatts-electric. The reactor has a 4-kW thermal uranium-molybdenum reactor core, sodium heat pipes for heat transfer and Stirling power converters created during the Advanced Stirling Radioisotope Generator program. A full nuclear demonstration is planned for late 2017 at the Nevada Nuclear Security Site. The demonstration is a partnership between NASA and the Energy Department's National Nuclear Security Administration.

Also this year, an Orion solar array wing was deployed inside the Space Power Facility at NASA Glenn's Plum Brook Station. The deployment of the 7.3-meter wing qualification model was an important first step to verify Orion's power system before **Exploration Mission-1** in 2018. A NASA Space Launch System rocket will boost an unmanned demonstration version of Orion tens of thousands of kilometers beyond the moon. The solar array is based on the European Space Agency Automated Transfer Vehicle's X-shaped array of four panels. Together, the four panels will generate 11 kilowatts of power and span about 19 meters when extended. The array is a component of Orion's service module, which the European Space Agency is providing and Airbus Defense and Space is building to supply Orion's power, propulsion, air and water. ★

A year of designing, testing electric propulsion

BY ERIC PENCIL

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

Industry and government engineers made key advancements this year on electric propulsion for science spacecraft, commercial communications satellites, cubesats and human exploration missions.

Eight colloid micronewton thrusters on the **European Space Agency's LISA** (Laser Inteferometer Space Antenna) Pathfinder spacecraft were commissioned in February during the spacecraft's journey to its demonstration location in space, and then began counteracting disturbance forces to enable the science mission's gravimetric measurements. The thrusters, developed by Busek Space Propulsion and Systems in collaboration with NASA's Jet Propulsion Laboratory, now provide precision spacecraft control in normal operations and are the first operational electrospray thrusters in space.

The primary mission for the Dawn probe ended in June after it investigated the **dwarf planet Ceres**, but NASA approved an extended mission around the planet. Dawn's xenon-fueled ion propulsion system has operated for more than 48,000 hours and provided an acceleration of over 11 kilometers per second, both records.

Qualification testing of the **PPS 5000 Hall thruster** has begun at Safran Aircraft Engines, and the first flight set is nearing completion for an expected flight in 2017. The European Space Agency, Thales Alenia Space, and Airbus Defense and Space jointly selected the 5-kilowatt PPS 5000 for the Neosat new-generation telecommunications satellite platform. The first PPS 1350 Hall thrusters are being readied for delivery to Space Systems Loral. The first arcjet system, developed and built by Aereojet Rocketdyne for Boeing's 702 satellites, launched Aug. 24 on Intelsat 33e.

On the Asteroid Redirect mission, Boeing, Lockheed Martin, Orbital ATK, and Space Systems Loral completed solar electric design studies for the unmanned phase of the mission, called **Asteroid Redirect Robotic Mission**, or ARRM. NASA's Glenn Research Center in Ohio and JPL have continued development of a 12.5 kilowatt Hall thruster system through wear testing, environmental testing, and integration testing of the thruster and power processing unit. ARRM entered phase B, meaning the definition phase, in August and is targeting a launch readiness date of December 2021.

CalTech/Jet Propulsion Laboratory

A colloid thruster accelerates charged droplets of liquid. This is the colloid thruster launched in 2015 on the NASA-European Laser Inteferometer Space Antenna Pathfinder technology demonstration spacecraft.

NASA's Evolutionary Xenon Thruster-Commercial project, or NEXT-C, completed a preliminary design review and received approval to transition to the implementation phase. The NEXT-C system is the baseline ion propulsion system for the Double Asteroid Redirection Test, led by Johns Hopkins University Applied Physics Laboratory.

George Washington University developed a **4-microcathode arc thruster propulsion system** for CANYVAL-X, short for Cubesat Astronomy by NASA and Yonsei University using the Virtual Telescope Alignment Experiment. This is a cubesat technology demonstration mission by NASA's Goddard Space Flight Center and Yonsei designed to validate technologies that allow two spacecraft to fly in formation along an inertial line of sight.

Busek, of Massachusetts, in collaboration with Glenn, is developing the newest generation of 100-micronewton electrospray propulsion subsystems. Flight hardware delivery for the six-unit cubesat **Pathfinder Technology Demonstrator mission**, led by NASA's Ames Research Center, is scheduled for 2017. Iodine electric propulsion continues with two Space Launch System Exploration Mission-1 payloads using iodine radio-frequency ion thrusters and the iodine satellite project to demonstrate iodine Hall thruster propulsion. Development of iodine propulsion components continues at Busek, Glenn, Colorado State University, NASA's Marshall Space Flight Center and VACCO Industries of California.

NASA continued work on 100 kW subsystems for human exploration. Aerojet Rocketdyne, the University of Michigan, JPL and Glenn are developing a nested-channel Hall thruster, which has been operated to thermal steady state at 16 kW. ★

New contracts, tech advances mark year in turbine engines

BY MICHAEL G. LIST, ASPI WADIA AND JANET CONVERY

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

Rolls-Royce

▲ **A Rolls-Royce Trent 1000 TEN** (thrust, efficiency, new technology) engine took to the skies for the first time on March 23 in Tucson, Arizona.

Rolls-Royce gas turbine engine technology has experienced another strong year, manifested in major technology development programs, development testing and certification of numerous engines, and continued investment in research facilities and quality education for future generations of gas turbine engineers.

In June, the **U.S. Air Force Life Cycle Management Center** awarded Ohio-based GE Aviation and Connecticut-based Pratt & Whitney each a $1 billion contract via the Adaptive Engine Transition Program to mature three-stream adaptive cycle engines. The AETP program seeks to demonstrate a 25 percent fuel-efficiency improvement, 10 percent increase in thrust and significantly improved thermal management. AETP is set to run through 2021 with extensive component, rig and engine testing.

GE Aviation began testing its first full **GE9X engine** in March at its Peebles, Ohio, testing facility. The test brought together all the GE9X technologies to demonstrate their operability as a complete propulsion system.

The **Rolls-Royce Trent 1000 Thrust, Efficiency and New Technology engine** took flight in March for the first time on a Boeing 747 test aircraft over Tucson, Arizona. The Trent 1000 TEN will power all Boeing 787 Dreamliner variants. The engine draws on technologies from the Rolls-Royce Trent XWB engine, delivering thrust and efficiency improvements. The Trent 1000 powered the first 787-8 entry into service in 2011 and the first 787-9 in 2014.

Williams International in Michigan was awarded the FAA Part 33 type certificate for its **FJ33-5A engine** in June. The new engine has more than 900 kilograms of thrust and market-leading fuel economy enabling a greater than 6-to-1 thrust-to-weight ratio, a breakthrough in FAA-certified single-engine jet aircraft. The FJ33-5A has been chosen to power the Cirrus Vision and the Flaris LAR1.

In July, the **Leading Edge Aviation Propulsion engine** marked its first delivery on the Airbus A320neo to Turkey's Pegasus Airlines. The engine is the newest from Ohio-based CFM International, a joint venture between GE Aviation and Safran Aircraft Engines. Additionally, the LEAP engine for the Boeing 737 MAX aircraft was certified in May with first delivery of the new aircraft scheduled for next year.

Facility upgrades at Penn State's Mechanical and Nuclear Engineering Department enabled the **Steady Thermal Aero Research Turbine lab** to complete its first test campaign from February through May. The facility upgrades included mass flow rate and temperature increases as well as additional instrumentation. Testing focused on sealing methods between turbine stages and interactions between the main gas path flow and cooling airflow. Results will be used to develop new predictive models for turbine designers, leading to increased component durability and higher engine efficiency.

The Gas Turbine Engines Technical Committee concluded another successful year of the Undergraduate Team Engine Design Competition at the **AIAA Propulsion and Energy Forum** in July. The goal was to design a replacement for the J-85 engine as a power plant for a new generation of trainer aircraft. The mission profile included a supersonic dash up to Mach 1.3 as well as cruise at Mach 0.85. Additional requirements focused on life, engine size, fuel efficiency and a low turbine inlet temperature. Teams around the globe submitted a record 13 reports. Based on the written reports, the top three teams were invited to participate in an oral presentation at the Propulsion and Energy Forum in Salt Lake City. The finalists represented the University of Cincinnati, Istanbul Technical University and the University of Kansas, with the top honors going to Kansas. ★

Contributors: *Daniel Jensen, John Sordyl, Jay Neal, Magdy Attia and Jimmy Tai*

NASA's Glenn Research Center; Air Force Research Laboratory

Progress seen in tech underlying high-speed flight

BY JOHN A. BOSSARD AND VENKAT E. TANGIRALA

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.

▲ **Researchers can** investigate mode-transition, such as from turbine to supersonic-combustion ramjet, with this representative inlet of a turbine-based combined cycle engine in a wind tunnel at NASA's Glenn Research Center in Ohio.

High-speed air-breathing propulsion technology is rapidly maturing to enable flight vehicles with revolutionary capabilities. This year saw important advances along a number of fronts: conceptual evaluation, analysis, hardware fabrication, ground testing and near-term flight test preparations.

With a strong foundation built upon the **X-51A WaveRider** program, the U.S. Air Force Research Laboratory, or AFRL, continued to advance scramjet and ramjet propulsion technologies under the High Speed Strike Weapon program. Preparations for direct-connect testing of two unique powerhead concepts through the Medium Scale Critical Components program are underway. These powerheads employ a common isolator and combustor and have mass captures approximately 10 times that of the X-51A engine. The common isolator and combustor hardware were fabricated and delivered to Arnold Engineering Development Center in Tennessee and will support the initial engine tests scheduled for early 2017.

In February, NASA's Glenn Research Center and AFRL completed phase 3B testing of the **Combined Cycle Engine Large-Scale Inlet Mode Transition Experiment**. Test results were used to characterize mode transitions at several transition speeds less than Mach 3.5. The AFRL/NASA team validated autonomous mode transition control laws and algorithms to enable smooth and stable inlet operation. They also investigated inlet distortion mitigation strategies during mode transition. Phase 3C is underway with the main goal of reducing risks for phase 4 testing, scheduled to start in 2018.

Researchers at NASA's Langley Research Center in Virginia continued to support development of numerical methods, ground testing and systems analysis relevant to hypersonic air-breathing propulsion, including formulation of the new **Hypersonic Technologies Project**. NASA has established a new facility funding model in which experimental efforts will be conducted at significantly reduced costs to NASA researchers and collaborators.

VULCAN-CFD, or **Viscous Upwind Algorithm for Complex Flow Analysis-Computational Fluid Dynamics**, development continues with the addition of hybrid structured-unstructured grid capabilities, which was to be ready for testing by the end of the year. As part of the Enhanced Injection and Mixing Project, experiments began in the Arc-Heated Scramjet Test Facility at Langley to better understand the physics of injection and to develop mixing enhancement strategies.

Progress on the **Hypersonic Flight Research program**, or HIFiRE, continued. In June, Douglas Dolvin, with the High Speed Systems Division at AFRL, addressed the status of the program and provided a review of plans for 2017. In May, he described milestones achieved in previous flights, including the completion of the flight vehicle critical design review. HIFiRE plans include evaluation of control strategies for hypersonic re-entry and cruise of shock-on-lip waverider design, characterization of adaptive control laws for lifting body configurations, and the investigation of hydrogen scramjet engine operability. These tests will be conducted at the Royal Australian Air Force Woomera Test Range in South Australia in March 2017.

Other developments are on the way. "In the future, beyond just the rocket plane, we can incrementally introduce further performance and reusability enhancements, and I think chief among them would be the addition of air-breathing propulsion," said Tom Markusic, CEO and founder of Firefly Space Systems, during a panel discussion at AIAA's Propulsion and Energy Forum in Salt Lake City in July.

Progress made this year by leading industry and government groups may enable the great potential of high-speed air-breathing propulsion to be realized. ★

Several hybrid rocket technologies hit advanced test stages

BY ORIE CECIL AND JOSEPH MAJDALANI

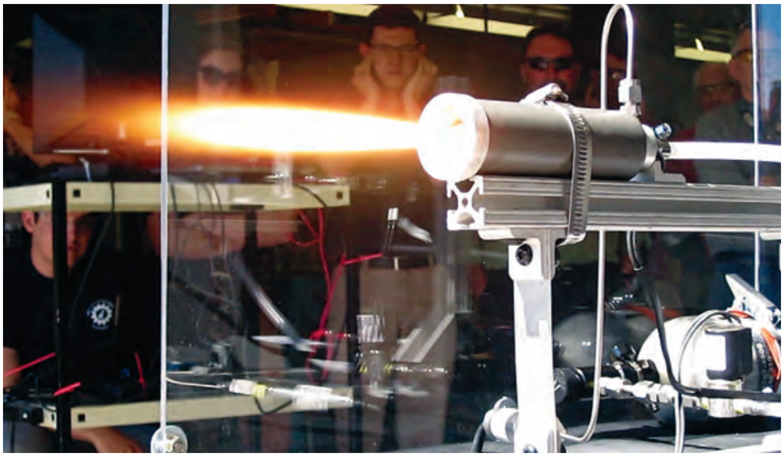
The **Hybrid Rockets Technical Committee** studies techniques applied to the design and testing of rocket motors using hybrid rocket systems.

The year witnessed the maturation of several hybrid rocket technologies into their advanced test stages in both industry and academia. It started loudly with the launch of the **Taiwanese APPL-9C** on Jan. 31 near Hsinchu City, Taiwan. The Advanced Rocket Research Center based in National Chiao Tung University developed this two-stage system, which featured a first-stage sugar rocket with a hybrid second stage that made use of nitrous oxide in a 3-D printed shell. The launch of the 27-kilogram-loaded, 2.7-meter-long rocket with a 15-centimeter diameter has paved the way for future tests of the larger HTTP-3 hybrid vehicle.

The NASA-funded Jet Propulsion Laboratory in California is developing a space-storable hybrid motor for a **Mars Ascent Vehicle**, or MAV, as part of the proposed Mars Sample Return mission. A comprehensive JPL-led trade study found a storable, single-stage-to-orbit, hybrid propulsion system to be the lowest mass option for a MAV.

At NASA's Marshall Space Flight Center in Alabama this year, a new, wax-based fuel developed by the Space Propulsion Group of California survived more than 200 Mars-like thermal cycles, emulating mission-like thermal profiles over a range of 50 to minus 115 Celsius (122 to minus 175 Fahrenheit). JPL is also funding hotfire testing of this fuel with nitrogen tetroxide. That testing is underway at SPG and California-based Parabilis Space Technologies.

▼ **Utah State University** tests a small hybrid rocket motor.



Utah State University

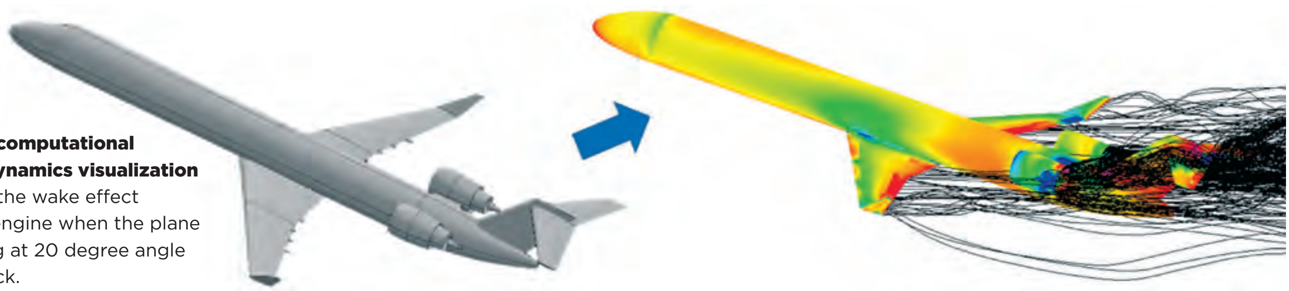
In the interim, researchers at Purdue and Penn State universities are investigating new solid additives to the fuel for hypergolic ignition to enable multiple starts of the hybrid motor as part of this program. JPL is in the planning stage for an Earth-based launch of a hybrid MAV, scheduled for 2019. Along similar lines, JPL is testing high-density polyethylene and polymethyl methacrylate with gaseous oxygen for cubesat applications. The goal of this three-year program is to demonstrate long-duration burns and multiple, autonomous ignitions to enable interplanetary cubesat mission concepts. Tests of up to 50 seconds were completed in 2016.

Utah State University received a $200,000 NASA grant to develop and test small rocket motors that could be used in lieu of hydrazine thrusters in small satellite applications. The motors are made of printed acrylonitrile butadiene styrene plastics with a meshwork of finely spaced voids. A voltage through the electrodes causes electrical charges to accumulate in the voids to the extent of building an arc in the core. Oxygen is then introduced to initiate burning. Testing is expected to begin in mid-2018 as the thruster payload is delivered to an altitude of 100 kilometers on board a NASA sounding rocket.

In May, Nammo AS, a company based in Raufoss, Norway, hotfired its **Flight-Weight Unitary Motor** intended for the Nucleus sounding rocket. Using hydrogen peroxide and hydroxyl-terminated polybutadiene, the test included two burns spaced by two hours and 35 minutes to demonstrate the engine's restart capabilities. Both burns produced stable combustion and 30 kilonewtons of thrust. This 800-kg, 9-m-long flight vehicle is the first member of the Norwegian North Star sounding rocket family. Nucleus will be launched in the first half of 2017 with a target altitude of 100 km and a payload of 70 kg.

In July, Gilmour Space Technologies, based in Singapore and Australia, launched its first test rocket as a first step toward its stated goal of reducing the cost of orbital and suborbital launches. The **Rasta rocket**, powered by nitrous oxide and dual 3-D printed fuel, achieved an altitude of 5 km.

Announced Aug. 1, the FAA granted Virgin Galactic an operator license to test **SpaceShipTwo**, a suborbital spaceplane, for two years over the Mojave Air and Space Port in California. The license allows the transport of scientific and experimental payloads but prohibits "spaceflight participants" until the reliabilities of SpaceShipTwo and WhiteKnightTwo, its carrier vehicle, have been carefully verified. ★



NASA

▶ **This computational fluid dynamics visualization** shows the wake effect on an engine when the plane is flying at 20 degree angle of attack.

Safety enhancements abound

BY NEAL HERRING, JONATHAN LITT AND RICHARD SCHARNHORST

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.

Technical committee members received approval from AIAA to change the name from Air-Breathing Propulsion Systems Integration to **Inlets, Nozzles and Propulsion Systems Integration**. The change was made to clarify that they directly support worldwide excellence in inlets and nozzles as well as propulsion systems integration. The committee retained "propulsion systems integration" to also highlight the focus on propulsion-airframe integration that is of growing interest to the community.

NASA, in conjunction with the FAA, has been working on several safety enhancements related to transport aircraft. One of these is **Airplane State Awareness — Simulator Fidelity**, with the goal of reducing incidents due to loss of airplane state awareness, as well as improving pilot performance during recovery from a full stall. NASA's role is to sponsor and undertake research to define aerodynamic model parameters necessary for replicating full-stall flight characteristics of various aircraft models. While these safety enhancements primarily focus on aerodynamic stall, it is also important to understand engine performance in these situations. Commercial engines are designed to operate over a limited range of attack angle. As the angle of attack gets larger, the airflow into the engine is reduced, resulting in reduced thrust and stability.

Researchers at NASA's Glenn Research Center have begun developing high-fidelity models of aircraft engines capable of operating at off-nominal conditions. The purpose of this work is to investigate commercial aircraft engine performance under extreme attitude conditions, taking into account such aspects as inlet distortion, wake effects, capture area variability and turbulence. This year, a variety of approaches — including **computational fluid dynamics**, or CFD, volume dynamics, stage-by-stage component modeling and parallel flow path modeling — have been used to develop a baseline model that will demonstrate the desired effects.

NASA is funding a multiyear study of gas-electric hybrid propulsion systems. It focuses on a conventional single-aisle twin-engine aircraft in which the propulsion fan can be driven by both the low-pressure turbine and a fan spool-mounted motor/generator. Under this study, **United Technologies Research Center**, or UTRC, in Connecticut has selected a concept of operations in which the motor/generator provides boost power during takeoff and climb, enabling the engine core to be sized at the maximum cruise condition.

The **hybrid geared turbofan** has the same overall pressure ratio as a conventional geared turbofan but with a 17 percent smaller core flow. With the smaller core, the hybrid requires a 2.1-megawatt motor to provide takeoff thrust and 1,500 kilowatt hours of stored energy for the takeoff and climb segments. With current technology batteries, electric components and thermal management system components, a hybrid geared turbofan-based airplane has much higher mission fuel burn than a conventional geared turbofan-based airplane for a 900-nanometer direct operating cost mission. However, the UTRC study showed that with improvements in electric components power density and thermal management systems capability, an approximately 6 percent reduction in Jet-A fuel consumption and 3 percent reduction in overall energy consumption for the mission is possible.

In July, researchers gathered in Salt Lake City for the **Propulsion and Aerodynamics Workshop** at the AIAA Propulsion and Energy Forum. Participants from industry and academia presented results for two configurations of relevance to the propulsion-airframe integration community: an S-duct diffuser with and without flow-control devices and a dual mixed-flow reference nozzle. This workshop is defining a rigorous process to obtain grid-independent CFD solutions and quantify the accuracy of different CFD codes, numerical schemes, turbulence models and overall solution methods, and using statistical analysis methods to compare CFD solutions to data. ★

Contributor: *Chuck Lents*

Focusing on rocket reusability, propellant efficiency

BY VINEET AHUJA AND DAVID L. RANSOM

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

Rocket reusability came into sharp focus this year with SpaceX and Blue Origin making significant strides. California-based SpaceX launched a series of communications satellites with its Falcon 9 rocket and landed its booster stage. In April, after launching a resupply mission to the International Space Station, it landed its booster stage on a drone ship at sea. Similarly, Washington-based Blue Origin demonstrated reuse of its **liquid hydrogen/liquid oxygen BE-3 engine** with four suborbital flights of its New Shepard rocket. The upper-stage variant, BE-3U, saw significant development, including the design of an extendable nozzle as part of the U.S. Air Force's Rocket Propulsion System program. Blue Origin's liquefied-natural gas/liquid oxygen BE-4 engine slated for Colorado-based United Launch Alliance's Vulcan launch system is undergoing risk reduction and powerpack testing at Blue Origin's West Texas site. As part of NASA's Commercial Crew Program, the landing system on SpaceX's Dragon 2 spacecraft underwent testing in McGregor, Texas, at the end of 2015. These tests included reduced-thrust firing of the Dragon's eight SuperDraco engines for a five-second hover test.

NASA conducted tests on Aerojet Rocketdyne's RS-25 engine, four of which will comprise the core stage of the Space Launch System. Building on the first SLS flight slated for 2018, which will use Aerojet Rocketdyne's RL10-B2 engine for the interim upper stage, NASA selected the **RL10-C3 engines** to power the exploration upper stage for the second and third SLS flights. In June, NASA and the European Space Agency conducted a critical design review for Orion's European-built service module that will propel Orion in deep space. The review culminates a series of reviews for three human exploration systems development programs that will enable the journey to Mars. The propulsion system of the module comprises three different types of engines and thrusters, including an orbital maneuvering system engine of space shuttle heritage that is undergoing acceptance and qualification tests.

Orbital ATK in Virginia revamped its Antares rocket, replacing the AJ-26 engines with **RD-181 engines**. The re-engineered rocket completed a 30-second hotfire test on the launch pad in May at Wallops Island in Virginia and in October resumed cargo launches to the ISS with its Cygnus cargo spacecraft.


Airbus Safran Launchers

▲ **The reusable thrust** chamber for a liquid oxygen/methane engine is hot-fired at the German Aerospace Center's site in Lampoldshausen.

In Europe, Airbus Safran Launchers continued development on Vulcain 2.1 and upper-stage Vinci propulsion systems for the Ariane 6 launcher. Between December 2015 and October this year, ASL carried out hotfire tests of its reusable **400-kilonewton LOX/Methane thrust chamber demonstrator** at the German Aerospace Center, or DLR, in Lampoldshausen, proving combustion performance and re-ignition. The construction of a facility to test the upper stage of the Ariane 6 launcher at DLR-Lampoldshausen was initiated in June.

NASA's **Green Propellant Infusion Mission** involving Ball Aerospace of Colorado, the Air Force and Aerojet Rocketdyne took another step toward demonstrating the capabilities of a safer and more efficient propellant. In March, NASA announced that the mission's spacecraft passed a major flight-readiness milestone when it completed functional and environmental testing of its systems. In other green propellant work, Aerojet Rocketdyne is partnering with NASA's Glenn Research Center in Ohio and Goddard Space Flight Center in Maryland to revise a design for a 1-newton thruster; Massachusetts-based Busek, Glenn and NASA's Marshall Space Flight Center in Alabama are partnering to mature the Busek 5-newton green monopropellant thruster; Orbital ATK is partnering with Marshall and Plasma Processes LLC in Alabama to test an LMP-103S propellant-based 445-newton thruster.

The Satellite Servicing Capabilities Office made significant advances for NASA's **Restore-L robotic spacecraft** in maturing fluid transfer system technology equipped to extend the lifespan of satellites in orbit. Developments this year include testing the transfer of simulant propellants at flight conditions and developing a propellant transfer subsystem that allows the robotic servicer to transfer propellant to the client propulsion system. ★

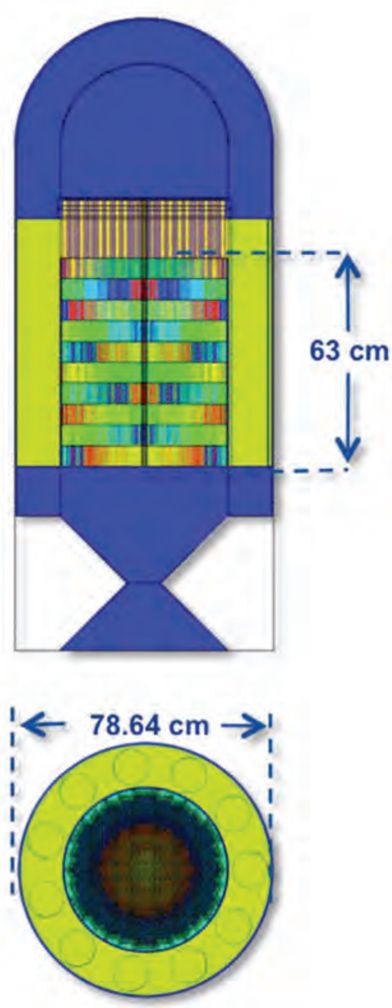
Exploring space for nuclear fuels

BY BRYAN PALASZEWSKI

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

NASA's Glenn Research Center in Ohio this year investigated atmospheric mining of the outer solar system as a first step in interstellar flight. The moons of these planets may be excellent storage and manufacturing facilities for building the elements and making the fuel of a starship. The nuclear fuels would be wrested from the planet's atmosphere and then delivered to a factory for processing. The moons' water ices would also be processed into oxygen and hydrogen for chemical propulsion landers. The landers would rendezvous with and supply fresh hydrogen propellant to the nuclear electric orbital transfer vehicles that deliver the atmospheric gases to the moons. The mass of several transportation systems for mining factories for Uranus and Neptune was estimated. **Miranda** (at Uranus) and **Thalassa** (at Neptune) would be promising small moons for propellant facilities. While the moons closest to the planets were the most attractive in terms of minimizing the transportation system mass, their gravity levels are quite low, which would make many fluid and propellant processes difficult to complete. Additional artificial gravity facilities on the moons would likely be needed for an effective propellant factory system. Even the largest moons of Uranus and Neptune have relatively low gravity levels, and they would also require artificial gravity facilities.

As a continuing line of research, improved reactor designs for power and propulsion are being investigated. While radioisotope power systems have been used for many robotic reconnaissance missions, using nuclear fission for large human and robotic science missions is vitally important. The concern has been raised regarding the importance of highly enriched uranium versus the recent suggestion of only using low-enriched uranium. **Low-enriched uranium** has been an issue in nuclear proliferation discussions; advocates believe the materials would promote the safety of nuclear systems on Earth. In general, the highly enriched uranium systems are very critical for spaceflight reactors to make them lightweight and compact. An option for the **highly enriched uranium reactor design** was released by the Center for Space Nuclear Research in Idaho, Aerojet Rocketdyne and the Ultra Safe Nuclear Corp. in New Mexico. The discussion regarding the two variants is an important ongoing issue in the nuclear technical community and the United Nations.

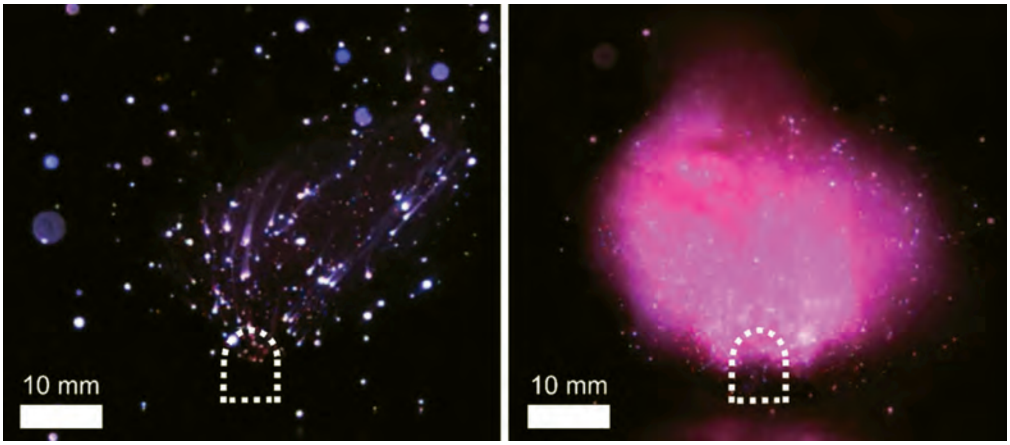


Center for Space Nuclear Research; Ohio State University; Ultra Safe Nuclear Corp; Aerojet Rocketdyne

▲ **In this conceptual design,** a fission reaction occurs among highly enriched-uranium fuel elements in the center of the cross section. The reaction heats hydrogen, which accelerates out a nozzle to propel the spacecraft. The reactor would be turned on once the spacecraft is beyond Earth's atmosphere.

Many international research groups have made claims regarding unusual physics that may lead to a better understanding and perhaps control of gravity. This year, researchers at the Dresden University of Technology in Germany conducted experiments and investigated numerous claims of gravity modification. After many careful steps in hundreds of experiments, the researchers showed that many effects noted by other research groups were part of extraneous signals or other electric interference. When meticulous steps were taken to electrically isolate the experimental equipment from the extraneous signals, the possibility of gravity modification was discounted and disproven.

In April, a group that includes a noted Russian billionaire and Stephen Hawking announced an ambitious proposal for interstellar flight. In this **StarShot** proposal, powerful gigawatt-class ground-based lasers would accelerate a very tiny spacecraft weighing only a few grams to 10 or 20 percent the speed of light. The spacecraft would be the size of a postage stamp and would have a gossamer light sail attached to intercept the powerful laser's energy. The energy flux on the StarShot would be extremely high; the proposed gigawatt-class laser power level would be equal to that of a space shuttle at liftoff. Although it is an extremely high-risk and challenging venture, StarShot may lead to other technological breakthroughs in communications, materials and propulsion. ★



▲ **Fuel comparison:** A strand of aluminum-lithium-alloy solid propellant called Alitec, right, glows magenta and burns more quickly with smaller droplets than a strand of aluminum-based propellant. The dotted lines are the locations of the propellant strands.

Improving efficiency and fuel ignition

BY STEVEN F. SON, TIMOTHY OMBRELLO AND CAMPBELL CARTER

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.

Traditional solid rocket fuel has two primary problems: The metallic fuel forms large molten droplets during combustion, resulting in up to a 10 percent performance loss that prevents the rocket from realizing its full range and payload capacity. It also emits highly toxic hydrochloric acid that is destructive to the environment and corrodes launch equipment, resulting in substantial maintenance and environmental remediation costs. Andranos Energetics LLC of Ilinois had been conducting research this year and last year in hopes of solving these two problems.

Working with Purdue University, Anranos Energetics is developing **Alitec**, the trade name for a propellant in which lithium is incorporated into the aluminum to form Al-Li, an alloy. This solid rocket formulation promises to enhance performance and virtually eliminate hyrdochloric acid production.

As with any solid propellant, Alitec is composed of three primary materials — a solid fuel anoxidizer and a binder. It is novel because Al-Li is used as the fuel instead of aluminum. Lithium by itself would be impossible to include because of its reactivity.

Initial research into Al-Li fuel in solid propellants demonstrated significant improvement in theoretical ideal specific impulse , which is the total thrust per unit mass of propellant compared to traditional propellant. The increase in performance is due to better combustion properties and higher efficiencies that are caused by a larger volume of gas being generated during combustion and the large disparity in boiling points of aluminum and lithium. This causes the metallic drops to micro-explode after they leave the surface of the propellant.

Alitec's performance enhancements would positively impact a wide variety of applications. For example, using Alitec in an air-to-air missile such as the **AIM-9 Sidewinder** would increase intercept range by as much as 14 percent, providing a significant tactical advantage in air-to-air combat. A surface-to-surface missile such as an MGM-140 ATACMS would travel up to 68 percent farther under a ballistic trajectory. For a space launch system, Alitec will allow for larger payloads to be delivered into orbit. Further work is needed to scale and characterize this propellant.

In research elsewhere, a new tool was developed and applied at the **Air Force Research Laboratory** in Ohio to establish an *a priori* ignition probability mapping for high-speed reacting flows. This work builds upon similar efforts by other research groups for gas-turbine-combustor ignition. As in previous work, the overall goal is to supersede time consuming empirical correlations that can be application-specific about where to deposit energy for robust ignition. Multiple targeted experiments of a **cavity-based flameholder** in Mach-2 flow have been performed at the Air Force Research Laboratory in Ohio to train and validate high-fidelity hybrid Reynolds-Averaged Navier Stokes/Large-Eddy Simulations of a fueled flowfield. Velocity distributions of the fueled, but non-burning cavity, were measured via particle image velocimetry. Nanosecond-gated, laser-induced breakdown spectroscopy was used to map the fuel-air concentrations while also providing an ignition source. The combined experimental and numerical approach has elucidated some of the controlling parameters of ignition. While the parameters of fuel concentration, turbulence intensity and shear play dominant roles at the point of energy deposition, they are also critical as the ignition kernel advects downstream. By using a **Lagrangian particle tracking method**, the parameter bounds could be invoked on the particle to simulate what the ignition kernel would experience. Overall the new approach has provided the first *a priori* ignition probability mapping for a supersonic combustor and has established a generic framework for additional refinement and interrogation. ★

Solid propellants make civil, military contributions

BY CLYDE E. CARR JR., AGOSTINO NERI AND ROBERT E. BLACK III

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 propulsion continued to set milestones in the industry with support to future and current launch systems and missile defense applications.

The U.S. Navy launched an unarmed Trident 2 D5 fleet ballistic missile from the Atlantic Ocean in August. It was the 161st launch since 1989. Lockheed Martin built the missile as well as a test element of the **Demonstration and Shakedown Operation 1**, or DASO-27, to certify the submarine's crew and weapon system. Both Aerojet Rocketdyne of California and Virginia-based Orbital ATK are major propulsion suppliers for the Trident 2 D5 missile.

Since NASA's Space Launch System program passed its critical design review in late 2015, Aerojet Rocketdyne and Orbital ATK continued development on the **Orion Launch Abort System** and booster propulsion systems. The LAS consists of three solid-rocket motor systems: jettison motor, abort motor and attitude control motor. In August, Aerojet Rocketdyne completed its third jettison motor test. In June, NASA and Orbital tested the second five-segment qualification booster, QM-2, at Orbital's facility in Promontory, Utah, at 4.4 Celsius, validating nozzle vectoring and motor performance and certifying the motor for flight.

Two or five Aerojet Rocketdyne **AJ-60A solid rocket boosters** per launch provided the thrust for liftoff of Atlas 5 launch vehicles. For first-stage separation, Orbital ATK provided eight retro motors per launch. Atlas 5's boosted a Navy Mobile User Objective System-5 satellite and GPS-Block 2F-12 satellites into orbit and an Orbital ATK Cygnus cargo spacecraft to the International Space Station. Meanwhile, with the Delta 4 launch vehicle, Orbital ATK GEM-60 SRMs were used for U.S. Air Force and National Reconnaissance Office payloads.

The Air Force awarded Aerojet Rocketdyne and Orbital ATK hardware demonstration and trade study programs in February to evaluate propulsion improvements and upgrades for retiring intercontinental ballistic missiles such as the Minuteman 3. In late 2015, Orbital ATK conducted a technology demonstration test with a Medium Class Stage 2 SRM demonstrating advanced technologies for the **Ground-Based Strategic Deterrent program**.

The U.S. Missile Defense Agency conducted several flight tests of ship-based systems. In a U.S.-Japanese flight test of Raytheon's **SM-3 Block 2A** off the coast of California, the joint missile test demonstrated fly-out through kinetic warhead ejection. In addition, the Aegis Ashore weapon system was tested during a first intercept test using an SM-3 Block 2B missile. A flight test of the **Ground-based Midcourse Defense** system followed in January to evaluate the performance of alternate kill vehicle divert thrusters. In May off the coast of Hawaii, two SM-3 Block 1B upgrade tests were flown, validating nozzle improvements for Orbital ATK's Third-Stage Rocket Motor. Both Aerojet Rocketdyne and Orbital ATK supply SM-3 propulsion stages and target vehicles for the MDA flight tests.

The U.S. Army's **PAC-3 Missile Segment Enhancement**, or MSE, missile upgraded in 2015 continued testing this year. Aerojet Rocketdyne provides the primary propulsion and attitude control motors to Lockheed Martin. In July, as part of a post-deployment test program, missile testing confirmed the ability to detect, track, engage and intercept an aircraft declaring the missile ready for hit-to-kill capability against lower-tier threats.

From Europe, the VEGA launch vehicle entered into full commercial phase in 2016 with the **PerúSAT-1/SkySats mission**, launched in September. The VEGA launch vehicle has three solid propulsion stages: P80, Zefiro 23 and Zefiro 9, manufactured by Avio Spazio, in Colleferro, Rome. The Ariane 5 launch system, equipped with two solid boosters built by Europropulsion, reached more than 85 flights. Ariane 6 and VEGA-C, the new European launch systems, entered into the development phase this year. ★

Aerojet Rocketdyne

◀ **The third development jettison motor** for NASA's Orion Launch Abort System fires for 1.5 seconds in an August test at Aerojet Rocketdyne's facility in Sacramento, California.

2020 Olympics seen as clean energy test

BY RYO AMANO, KEIICHI OKAI AND YUJI OHYA

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.

Japan plans to use the 2020 Olympic Summer Olympics and Paralympic Games in Tokyo to demonstrate the potential for developing **low-carbon-emissions communities** through the use of hydrogen technologies. The Ministry of Economy, Trade and Industry and Ministry of the Environment are promoting technologies for the production and utilization of hydrogen. The Olympics provide an opportunity for the workforce to demonstrate how low-carbon communities can be created through the combination of these technologies to produce and use carbon dioxide-free, hydrogen-based power at a lower cost. Japanese officials are urging the science community in Japan to create "energy carriers," such as ammonia and methyl-cyclohexane, so that they can store energy that may be converted later to other forms of work such as mechanical or heating. The government is trying to make the athletic village for the 2020 Olympics kickstart a transition to a hydrogen-powered society.

In the power storage field, several faculty members from the University of Wisconsin Milwaukee, UWM, opened small laboratories within the new battery research facility set up on campus in 2015 with the support of **Global Technology and Innovation**, a research center in Milwaukee operated by Johnson Controls Power Solutions. The battery facility is being shared with Johnson Controls, whose primary goal is to make rechargeable lithium ion batteries very reliable and less costly by simplifying the number of components and improving the in-cell monitoring function. That will be done by employing nanomaterials. Li-ion batteries are useful in hybrid-powered vehicles because they are lightweight, maintain their charge for a long time and have a higher power density than many other energy sources. The development of these batteries will significantly promote and help internal-combustion engine-based automobiles shut the engine off when the vehicle is idling to save fuel use and emissions. Work is underway on nanoscale in-cell sensors that will monitor conditions including heat inside the battery. UWM researchers are working on tin-based materials to enhance Li-ion anodes. The anode and cathode are the parts of a battery that facilitate the chemical reaction that creates an electrical current.

In the field of wind energy, UWM's College of Engineering and Applied Science conducted research this year in a 30-meter high, 12-kilowatt wind turbine on the campus. The researchers captured power from the wind and monitored it through the system's microgrids, which are part of the system that converts wind energy to electric energy. This wind power research is coordinated by the **Midwest Energy Research Consortium**. In addition, new shrouded wind turbines are being designed and tested in Japan at the **Research Institute for Applied Mechanics** at Kyushu University. Such shrouded wind turbines equipped with a flanged diffuser demonstrated power augmentation for a given turbine diameter and wind speed by the power coefficient of about 2 to 5 compared to a standard (bare) wind turbine.

Hydropower is an important source of renewable energy in the U.S., given the approximately 80,000 dams in the country. The majority of these dams are older than 50 years and will need to be improved. To support that need, UWM in July finished setting up a lab for hydro turbine research at the university's **Global Water Center**, under the sponsorship of U.S. Department of Energy. Researchers will test various technologies with the goal of more efficiently converting water currents into electricity. In particular, researchers will experiment with a Kaplan turbine, which is one sized for laboratory research. ★

Kyushu University

▼ **Kyushu University has been investigating** a diffuser augmented wind turbine, called a wind-lens turbine, at its campus in Japan.

Testing the waters under the sea, on a volcano

BY JOE CHAMBLISS AND JONATHAN METTS

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

NASA

◀ **Crew members** participating in the NASA Extreme Environment Mission Operations do underwater "spacewalks" as part of evaluating tools and techniques for future space missions.

The Life Sciences and Systems community is actively conducting research and planning to enable human exploration of space.

NASA's One-Year Mission concluded in 2016 with astronaut Scott Kelly and Russian cosmonaut Mikhail Kornienko's return to Earth. Investigators have received most of the blood samples taken from Kelly in orbit and from Kelly's twin on the ground as well as samples from the twins six months after Kelly returned to Earth. Batch sample analysis has begun. Results will be presented at the January Human Research Program Investigators' Workshop in Galveston, Texas.

NASA's Space Biosciences Division has validated its **International Space Station WetLab-2** system, which conducts real-time gene expression analysis, and in April, NASA astronaut Kate Rubins performed the first gene sequencing in space.

In July, a team at NASA's Johnson Space Center, or JSC, in Houston completed testing to evaluate effects of carbon dioxide on cognition and decision-making in crewlike subjects. Twenty-two subjects performed tests during exposure to carbon dioxide concentrations of 600, 1,200, 2,500 and 5,000 parts per million. Steps were taken to ensure subjects and investigators were blind to the test conditions. Results will be used in defining exploration carbon dioxide requirements.

The **Wearable Kinematic Systems project** by Massachusetts-based Charles Stark Draper Laboratory developed a small, unobtrusive, wearable kinematic vision and inertial system to estimate how astronauts interact with the vehicle-habitat. The team completed hardware demonstrations in June at JSC.

The **NASA Extreme Environment Mission Operations 21 mission** was completed in August. Inside the undersea habitat, a crew of six aquanauts tested a DNA sequencer, a medical telemetry device and the Microsoft HoloLens.

An international team of six completed a yearlong analog simulation in a domed facility in the Mars-like environment of the Mauna Loa volcano in Hawaii as part of the Hawaii Space Exploration Analog and Simulation program. The crew was mostly self-sufficient and only left the habitat while suited for simulated extravehicular activities.

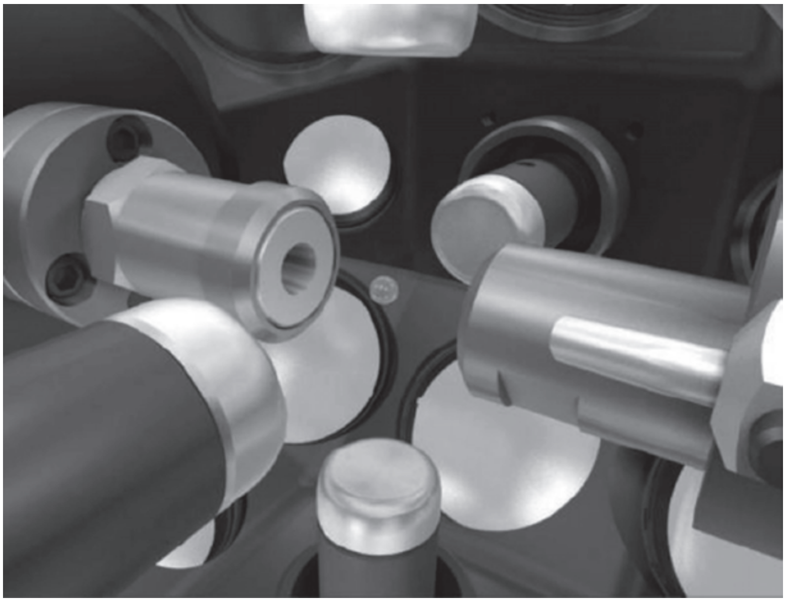
The European Space Agency and other European agencies have been very active with life sciences onboard the ISS. The ESA experiment **Spheroids** is investigating the effects of weightlessness on tube formation, differentiation and the mechanisms of apoptosis in human endothelial cells. Kayser Italia, based in Livorno, Italy, completed manufacturing of the Advanced Closed Loop System flight model avionics and delivered it to Airbus DS for integration and launch in 2017. CNES, the French space agency, is preparing 12 instrument and technology demonstrators for human physiology for ISS experiments that will be operated by Italian astronaut Paolo Nespoli and French astronaut Thomas Pesquet.

The **EDEN ISS Antarctic greenhouse project** completed a two-week study at the German Aerospace Center in Cologne. Subsystem development and plant growth trials are ongoing.

The NASA Advanced Exploration Systems Life Support Systems team is addressing technology gaps to improve reliability and further close the air and water recovery loops. Major milestones completed this year include delivery of the aerosol sampler for flight demonstration on ISS and major design reviews for a spacecraft atmosphere monitor and the brine dewatering system.

NASA's Human Exploration Spacecraft Testbed for Integration and Advancement at JSC continued unmanned testing including an electrolyzer, human metabolic simulator, air revitalization system and wireless sensors in an integrated environment.

Delaware-based ILC Dover delivered the **Z-2 exploration suit** prototype to JSC in early 2016. Features of the Z-2 include rear-entry donning, nominal operation at 4.3 or 8.2 pounds per square inch, titanium bearings, impact-resistant composite hard upper torso, planetary walking boots, compatibility with suit ports, integrated audio system and adjustable sizing in the upper torso, waist, arms and legs. Teams tested the Z-2 suit to evaluate the carbon dioxide washout performance at ambient pressure and also completed an evaluation of the sensor glove in an underwater suited training environment. ★


NASA

▲ **This arrangement of electrodes** inside the Electrostatic Levitation Furnace provides the electrostatic force to hold the sample in position. The ELF was launched last year by the Japan Aerospace Exploration Agency.

Experiments progress on thermophysical properties

BY MICHAEL P. SANSOUCIE, DAVID L. URBAN AND STEVEN H. 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 **Electrostatic Levitation Furnace** (ELF) launched last year by the Japan Aerospace Exploration Agency is designed to measure the thermophysical properties of metal oxides, levitate materials and hold its position with three-axis Coulomb force. Microgravity enables high-quality thermophysical property measurements for properties and materials that are sensitive to gravity-driven phenomena such as buoyancy-driven fluid flows and sedimentation. Electrostatic levitation in space offers very quiescent and very well-controlled fluid flow, which is required for precise measurements of thermophysical properties. Furthermore, the environment of ELF allows for a high degree of control over transport processes that cannot be achieved on earth.

Research on the ELF has continued throughout 2016. NASA selected four U.S. investigators to utilize ELF for thermophysical properties experiments. Topics range from novel methods to measure interfacial tension to the measurement of thermophysical properties of metal oxides and photorefractive materials, as well as studies of how to get the best properties from levitation, both on ground and in space.

Experiments on the European Space Agency's **Materials Science Laboratory Electromagnetic Levitator** (MSL-EML) have been underway since April 2015. There are three U.S. investigators who are part of the agency's topical teams with experiments on the MSL-EML. Those experiments are split into batches of 18 samples.

Samples processed so far include Vitreloy 106a (Vit106a), iron-chromium-nickel (FeCrNi), zirconium (Zr), Copper-cobalt (CuCo) alloys, an iron-cobalt (FeCo) alloy, and a nickel-tantalum alloy with added tantalum oxide (NiTa+Ta2O5). **Vit106a** is a zirconium-based bulk metallic glass-forming alloy with very interesting properties. Iron-chromium-nickel (FeCrNi) is an alloy that is similar to some stainless steels. Zirconium is used as a reference material. The copper-cobalt alloys are being studied to investigate undercooling and demixing, and surface tension and interfacial tension of these immiscible alloys. The FeCo alloy allows studies of double recalescence and metastable states. Many of these samples will continue to be processed in Batch 1.2c, plus a new class of nickel-based super alloys will also be processed in Batch 1.2c.

Electromagnetic levitation on ground has high stirring. This is reduced in space but still there. By performing experiments in space and on ground, scientists can study the effects of flow velocity on nucleation.

Understanding how fire spreads in a microgravity environment is critical to the safety of astronauts who live and work in space. And while NASA has conducted studies aboard the space shuttle and International Space Station, risks to the crew have forced these experiments to be limited in size and scope. The first spacecraft fire experiment, called **Saffire-I**, was conducted June 14-19 in Orbital ATK's Cygnus vehicle to investigate large-scale flame spread and material flammability limits in long-duration microgravity. Although the fire was contained in the Saffire module, the experiment used the entire pressurized volume as the test atmosphere. This novel use of ISS cargo vehicles demonstrated a new capability for experimentation and revealed significant effects of both sample and test chamber size on material flammability.

A new era in physical sciences research in spaceflight began this year in April and June with Blue Origin's third and fourth flights of its **New Shepard rocket**.The flights, using the same booster and capsule, carried several "Pathfinder" science payloads from researchers in the U.S. and Germany. Because of these flights, commercial, reusable, suborbital rocket flights for research are now available to researchers to purchase. ★

Lockheed Martin

◀ **A Patriot Advanced Capability Missile** Segment Enhancement is launched in March by the U.S. Army at White Sands Missile Range, New Mexico. The missile tracked and intercepted a tactical ballistic missile target.

Global tensions spur missile advances

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.

Rising tensions in world hot spots continued motivating the development of missile system technologies this year. Russia's sale of sophisticated weapons to Iran following the nuclear deal negotiated by the Obama administration and ballistic missile tests by North Korea have prompted renewed interest in air and missile defense systems.

The U.S. Army funded improvements to the Patriot Air and Missile Defense system developed by Raytheon and Lockheed Martin. Among these upgrades are the Patriot Advanced Capability-3 Missile Segment Enhancement, or **PAC-3 MSE**, a high-velocity hit-to-kill interceptor with a dual-pulse solid rocket motor and larger control fins providing nearly double the range and increased maneuverability. PAC-3 MSE completed several engagements against tactical ballistic missiles, cruise missiles and aircraft over the White Sands Missile Range in New Mexico before being accepted into service in August.

The U.S. Navy tested ship-based air defenses during evaluation of Raytheon's **SeaRAM** at the Point Mugu Sea Range in California. SeaRAM combines the Rolling Airframe Missile with the radar of a Phalanx self-defense gun to acquire, track and destroy threats like anti-ship missiles, unmanned aerial vehicles or aircraft. During a May test, SeaRAM successfully detected, tracked and engaged two incoming supersonic cruise missiles using RAM Block 2 missiles to intercept the targets.

Another region of international tension has been the Western Pacific where China and neighboring countries dispute ownership of several island chains, prompting continued investment in anti-ship missiles. A significant accomplishment was the successful completion of operational testing by Raytheon's **Joint Stand Off Weapon C-1 variant**. Entering service with the U.S. Navy in June, the JSOW C-1 air-launched missile adds a Link 16 data link capable of receiving target updates during flight to track a moving ship.

Though the first network-enabled weapon in the Navy's inventory, JSOW will soon be joined by the upgraded Boeing Harpoon Block 2+ anti-ship missile that incorporates the same data link radio to provide improved targeting precision. Harpoon 2+ made its first flight in late 2015 and is expected to reach initial operational capability next summer. Boeing continues improvements with an extended range variant flying nearly twice as far thanks to a new engine and increased fuel capacity.

As armed conflict continues from Syria to Afghanistan, improvements in ground attack weapons are also underway. The United Kingdom declared operational capability of the enhanced **MBDA Brimstone 2** missile in July following a successful series of trials at the U.S. Naval Air Weapons Station at China Lake, California. The Royal Air Force tests confirmed an increase in engagement envelope, performance against targets at high off-bore sight angles, and effectiveness of a new warhead against fast-moving armored and nonarmored vehicles.

The U.S. Marine Corps improved its capabilities by introducing a new variant of the **Advanced Precision Kill Weapon System** in March. Designed by BAE Systems, the system turns unguided 2.75-inch rockets into guided missiles by adding a semi-active laser guidance and control section. The improved kit is modified for use on fixed-wing aircraft to provide a low-cost, low-collateral damage, high-precision attack capability from the service's Harrier jets.

Two areas of research also suggest future directions for missile systems. The Pentagon has expressed particular interest in high-speed technologies. Building on past flights of the X-51 WaveRider that achieved hypersonic velocities of Mach 5 using a scramjet engine, the U.S. Air Force is accelerating development of a follow-on demonstrator. Interest has also been shown in deploying directed energy payloads aboard cruise missiles. Following the **Counter-electronics High-power Microwave Advanced Missile Project** that disabled a bank of computers in 2012, researchers look to integrate an improved Raytheon directed energy payload aboard Lockheed's Joint Air-to-Surface Standoff Missile. ★

Diverse efforts target living in space

BY MARIA JOÃO DURÃO, BARBARA IMHOF 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.

Europe's first transportable space analog habitat, the **Self-deployable Habitat for Extreme Environments**, or SHEE, was declared functionally complete and available for use by scientists and engineers in January for analog missions. Then on April 18-22, SHEE was deployed to Rio Tinto, Spain, and used for the Mars simulations of Project Moonwalk.

During the simulations, exobiological procedures and manual sampling techniques were performed and tested, searching for remnants of life. Valuable samples were analyzed with the Signs of Life instrument at the astrobiology laboratory in the SHEE with positive results. Further, simulation astronauts tested egress and ingress procedures from a planetary habitat through a suitport when donning their suits.

The **Bigelow Expandable Activity Module**, or BEAM, arrived at the International Space Station on April 10 in the trunk of a SpaceX Dragon cargo vehicle. After berthing it at the aft port of the Tranquility module on April 16, the ISS crew inflated it to its working volume of 16 cubic meters on May 28 over a period of seven hours.

The inflation process was not without hiccups. The first attempt on May 26 was halted after two hours of failing to expand, despite higher-than-expected internal pressure. That might have been due to its longer-than-anticipated compact storage on Earth. Nevertheless, after a two-day interlude, the deployment resumed and was ultimately successful.

ISS crew members will enter the module periodically over the next two years to assess its habitability, taking measurements of atmospheric quality and radiation levels. Glenn Miller, NASA's principal investigator for the experiment, estimates BEAM's technology readiness level to be TRL-7; at TRL-9 the technology will be certified for human habitation. This iteration of BEAM is scheduled to unberth from the ISS in 2018 and burn up in the atmosphere after an unpropelled orbital decay lasting less than a year.

Continuing efforts have been made to advance the technology readiness level of 3-D printing for space applications. The European Space Agency and the European Commission share the U.S. classification of 3-D printing as a critical technology and have awarded projects in this area. Here, the focus lies not only on the structural optimization of 3-D printed components but also in proving that meaningful habitation structures could be printed from Martian or lunar sand. Thus, different sintering techniques and processes using or not using soil-binding materials are being tested. Under the lead of DLR, the German Aerospace Centre in Cologne, the **project RegoLight** is being developed as part of the EU-H2020 framework program for research and innovation. Both in the solar oven of the Cologne center and in a vacuum chamber close by, different types of interlocking building elements will be solar-sintered using lunar simulant sand to demonstrate the options for building a variety of lunar base architecture elements made only from the sun and the lunar soil.

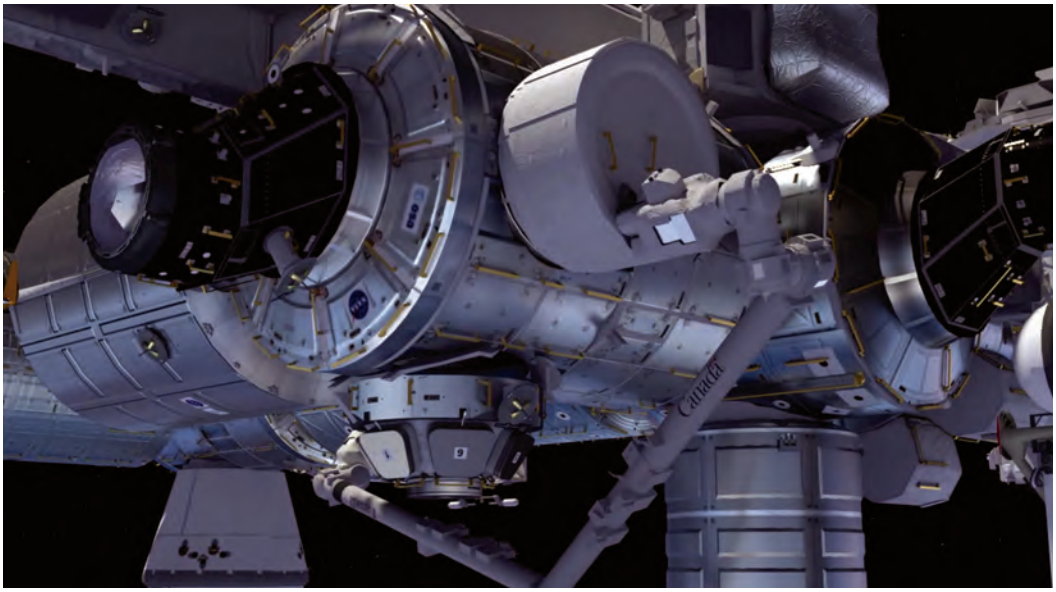
NASA's Johnson Space Center in Houston is home to the **Human Exploration Research Analog or HERA**, formerly known as the Deep Space Habitat. This Earth analog is a high fidelity mock-up where crew members perform operational tasks and simulations that closely parallel the workday duties, general housekeeping and maintenance of the ISS. Diet, schedule and many other variables are made identical to the ISS to carefully evaluate crew interaction with flight-like hardware in established controlled conditions. More than 30 independent and overlapping studies dovetail with ISS studies.

Investigators are looking at psychological and human factors and physiological impacts based upon isolation, remoteness and confined habitation. The NASA Johnson Flight Analogs Project routinely recruits future volunteers. ★

Contributor: *Sandra Haüplik-Meusberger*

Moonwalk Consortium/Bruno Stubenrauch

▼ **Researchers set up** the Self-deployable Habitat for Extreme Environments in Rio Tinto, Spain, in April, partly to test sampling techniques for a future Mars mission. The flag is that of the European Union.



NASA/Johnson Space Center; Bigelow Aerospace

This image taken in May shows the experimental Bigelow Expandable Activity Module, or BEAM, attached to the International Space Station in the center of the photo but not expanded yet. BEAM is designed to validate the benefits of expandable habitats in space.

Small steps made toward humans settling in space

BY ANITA GALE, RON KOHL AND MIKE SNYDER

The **Space Colonization Technical Committee** promotes the development of advanced concepts, science and technology to enable and enhance permanent human presence in space.

Incremental progress continued to be made in 2016 toward the long-term goal of human settlement in space.

Some progress came in areas not directly related to aerospace. For example, self-driving taxis were deployed in Singapore in August. The technology of **self-driving cars** will be valuable for future infrastructure on the moon and planets, e.g., long-haul driverless transport of ores from remote locations to refineries and/or launch sites.

Three-dimensional printing is a critical technology for future space settlement, enabling long-term operations without requiring huge logistics inventories of spares. The Juno spacecraft arrived at Jupiter in July and is the first spacecraft to fly 3-D printed titanium parts, NASA says. California-based Made in Space Inc., which pioneered 3-D printing in space on the International Space Station, launched and began operations in April with its second orbital unit at ISS.

The U.S. government made progress, too. In August, the FAA granted permission for private company **Moon Express** in Florida to land a vehicle on the moon. CEO Bob Richards said the company's plan is to make money extracting lunar resources. In March, U.S. Rep. Dana Rohrabacher, R-Calif., introduced the Space Exploration, Development, and Settlement Act to make development and settlement of space part of the law governing NASA. The Senate Commerce, Science, and Transportation Committee amended the NASA Transition Act of 2016 in September to include "long-term goals of the human space flight and exploration efforts of NASA." Part of the amendment ensures "the peaceful settlement of a location in space or on another celestial body and a thriving space economy in the 21st century."

Reusability of commercial launch vehicles saw milestones, with SpaceX landing a Falcon 9 first-stage rocket on a drone ship in April, May and August. After the first return of a Falcon 9 to its launch site in December 2015, SpaceX completed a second return in July. The company responded to skeptics' questions by announcing in August that its first reflight of a Falcon 9 was to be with a communications satellite in the fall, although questions about the economics of Falcon 9 reflight remain, and an explosion during a September test at Cape Canaveral, Florida, affected the launch schedule. Blue Origin's New Shepard accomplished reflights in January and April of vehicles returned from suborbital flights. The championship for reusability, however, belongs to the **Boeing X-37B**, with a second vehicle well over a year into its second flight as of this writing.

A milestone toward commercially operated space habitats was accomplished with inflation in May of the Bigelow Expandable Activity Module, or BEAM, attached to the ISS. NASA spokesman Daniel Huot called BEAM "the first expandable human-rated habitat to ever be flown into space." In September, Elon Musk of SpaceX announced plans to expand commercial interests to Mars, with a transport system based on full reusability, refueling in Earth and Mars orbits, and methane/oxygen propellant that could be manufactured on Mars. ★

Space logistics providers find their way

BY ERIC A. JACKSON

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

Space logistics in 2016 saw commercial providers truly come into their own, shipping vital supplies to the International Space Station and then returning essential scientific products as well as key station equipment that needed repair or assessment to Earth-bound operations.

Not only did the supply chain get "closed" through this renewed ability to launch and retrieve cargo, **SpaceX** achieved multiple recoveries of core launch transportation system components — first stages — from transits both to low Earth orbit and geosynchronous Earth orbit demonstrating a marked advancement toward reliable, lower-cost transportation both to orbit and, potentially, into interplanetary transits.

SpaceX accomplished this while responding to the challenges resulting from the loss of two launch vehicles, one in flight in 2015 and the other on the ground in September. These losses indicate that while the space transportation leg of space logistics is advancing rapidly, much work remains to achieve the reliability and responsiveness seen in the more mature aviation logistics enterprise.

Throughout 2016, the ISS program prepared for a busy manifest schedule delivering cargo and crew in the coming years. Installation of the **Common Communications for Visiting Vehicles** system and the first international docking adapter will support Orion and NASA commercial partners. Preparation has included a re-baseline of operating environmental control systems and additional crew quarters for planned increase of nominal crew size. Additionally, ISS continued upgrades to its **Command and Data Handling System** to support payload providers.

▼ **Shown is the launch** of the cargo resupply mission to the International Space Station in April, which was followed by the recovery of SpaceX's Falcon 9 rocket core stage.

SpaceX

NASA also added the requisite docking structures to enable future commercial cargo and manned transit to the ISS. On the ground, mission evaluation has transitioned to **Mission Control Center for the 21st Century** offering mission control flexibility through a more distributed architecture.

In the area of Mars research, researchers working on the NASA-sponsored **"2016 Mars Water In-Situ Resource Utilization** (ISRU) **Planning Study,"** announced and discussed an array of findings, including that four previously identified landing sites have a "realistic potential" to be considered as water reserves for human explorers. The findings were discussed in June at the 7th Space Resources Roundtable and the Planetary and Terrestrial Mining Sciences Symposium in Golden, Colorado. Also at the event, United Launch Alliance presented its "Cislunar 1000 Vision"—a 30-year road map in which lunar resources would enable a growing space economy. ISRU continues to be a major focus for space logistics researchers as a key enabler of human expansion into the Earth-moon-Mars system.

On the extra-orbital sustainment front, researchers at the Massachusetts Institute of Technology, NASA Jet Propulsion Laboratory and Keio University in Tokyo have analyzed the potential of lunar ISRU to develop a fuel infrastructure in **cislunar space** as a potential gateway for repeated human Mars missions and settlement later in the 21st century. It was found that up to 68 percent mass savings can be achieved on a recurring basis using lunar oxygen at a behind-the-moon fuel depot, assuming that the productivity of ISRU infrastructure can achieve levels of 10 kilograms a year for each kilogram of plant mass. This technology could become one of the pillars of a future interplanetary supply chain and has been referred to as a worthwhile "detour to the moon."

Ultimately, the successes — and failures — experienced in 2016, combined with continued advancement in orbital, lunar and interplanetary logistics and supportability concepts, show convincingly that space logistics remains on a fast track. Continued work by commercial and government entities to standardize logistics procedures while developing improved tools and techniques for transportation, communication, packaging, handling and other vital logistics elements will ensure future space operations are able to be deployed, sustained and re-deployed cost effectively and efficiently. ★

Contributors: *Leif Anderson, Olivier L. de Weck and Robert Shishko*

Commercial partners are expanding access to space

BY ERICA RODGERS

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

A major theme in space systems during 2016 was the expanded presence of commercial partners to enable crew and cargo capabilities, as well as flight test opportunities. Several of these partners offer reusable systems as the future operating model of access to space.

Throughout the year, NASA sent science and research experiments and cargo to the International Space Station via the Commercial Cargo Program. Orbital ATK launched a **Cygnus** spacecraft using an Atlas 5 rocket to the ISS on separate cargo missions in December 2015 and March, and launched its sixth cargo resupply mission from the Wallops Flight Facility, Maryland, in October using an Antares rocket. The Cygnus spacecraft housed a large-scale flame spread and material flammability experiment conducted during re-entry on the fifth cargo resupply mission.


Blue Origin

▶ **Blue Origin's New Shepard booster** executes a controlled vertical landing at 4.2 mph in January after both the capsule and booster reached an altitude of over 333,000 feet.

SpaceX launched two cargo missions, its eighth and ninth, in April and July using the Dragon spacecraft and **Falcon 9 rocket** from the Cape Canaveral Air Force Station in Florida. SpaceX for the first time succeeded at landing the first stage of the Falcon 9 on a droneship in the Atlantic Ocean following the April 8 launch of a Dragon cargo spacecraft to the ISS.

Sierra Nevada Corp. continues to work toward certification of its **Dream Chaser** spacecraft for cargo transfer to and from the ISS. The company passed the second Integration Certification Milestone in July in preparation for a minimum of six cargo delivery missions between 2019 and 2024.

Partners of the **Commercial Crew Program** continue to prepare to ferry crew to and from the ISS. SpaceX's Crew Dragon spacecraft is now planned for use in two operational missions, as is Boeing's CST-100 Starliner spacecraft.

NASA's commercial partners prepare to expand the number of available technology maturation testing platforms through NASA's Flight Opportunities Program. In June, Blue Origin was selected to provide suborbital flights aboard its New Shepard rocket and capsule to test technologies in microgravity. Blue Origin demonstrated its reusable systems through a booster vertical landing, followed by re-use of the hardware for successive flights.

Virgin Galactic, another commercial partner, unveiled the **Virgin Spaceship Unity** in February to replace the original SpaceShipTwo that broke apart during a test flight in 2014. The Unity was subsequently awarded an FAA operator license for commercial operations.

Partners in the Commercial Crew and Cargo Program will continue to transfer cargo to and from the ISS during 2017, as well as prepare for planned crew transfers in 2018.

Other 2016 highlights included:

• The joint U.S.-European Earth observing satellite, **Jason-3**, launched in January aboard SpaceX's Falcon 9 rocket from Vandenberg Air Force Base, California. This is the fourth in a series of satellite missions that measure the height of the ocean surface. Jason-3 uses a radar altimeter to measure sea-level variations over the global ocean with very high accuracy.

• Early this year, NASA successfully completed a comprehensive review of plans to modernize the ground support systems at Kennedy Space Center, Florida, in preparation for the first Space Launch System/Orion launch in 2018. In May, the **Orion pressure vessel** passed a pressurization test at Kennedy; in June, the final qualification test of the SLS solid rocket booster took place at Orbital ATK's Promontory Propulsion Systems facility in Utah, and in July, the SLS RS-25 rocket engine underwent a successful developmental test at NASA Stennis Space Center, Mississippi.

• After a five-year journey, NASA's **Juno** spacecraft entered Jupiter's orbit on July 4 following a 35-minute Leros 1-pound main engine burn. Juno's suite of nine instruments will improve our understanding of the origin and evolution of Jupiter, and thus our understanding of the solar system's beginning. The primary science mission began in October when another engine burn moved the spacecraft into a 14-day orbit designed to cover the entire planet. ★

The H-2 Transfer Vehicle is shown at the Tanegashima Space Center in Japan in October. The Japan Aerospace Exploration Agency is developing an electrodynamic tether that will launch in late 2016 or 2017 aboard the H-2.

JAXA

Another year of advances for tethers community

BY SVEN G. BILÉN

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

The space tethers community saw new developments in 2016, which included the Japan Aerospace Exploration Agency continuing to develop the **Konotori Integrated Tether Experiment**, or KITE, a flight demonstration of an electrodynamic tether. It is now planned for launch in late 2016 or early 2017, delayed in order to address a problem with the H-2 Transfer Vehicle uncovered during launch preparations.

KITE will demonstrate key technologies for active debris removal using electrodynamic tethers through a zenith-deployed, 700-meter-long bare tether that collects electrons from the ambient space plasma and a field-emission cathode on the H-2 Transfer Vehicle that emits 10-milliamp-level current, hence providing propellant-free deorbit propulsion.

Star Technology and Research of South Carolina and subcontractors Tether Applications of California, Electrodynamic Technologies of Minnesota and the U.S. Naval Research Laboratory matured key components, features and operations of their **ElectroDynamic Delivery Express**, or **EDDE**, spacecraft. A new 12U cubesat–sized "mini-EDDE" can distribute nanosatellites from the International Space Station to Sun-synchronous orbit. A new precious-metal steam resistojet, which has a specific impulse of around 200 seconds, can raise EDDE above the ISS and drive EDDE's "born spinning" deployment. EDDE's rotation stiffens the long conductor and improves agility by allowing a wider range of conductor angles to the Earth's magnetic field. That allows EDDE to change orbit plane at greater than 1 degree per day, and climb or descend hundreds of kilometers per day, even in polar orbit. Electrodynamic Technologies developed ways for EDDE to actively avoid all tracked objects. The Naval Research Lab developed methods to track persistently thrusting objects, including tethers and other objects that form fuzzy or irregularly glinting radar targets.

Two Spanish companies, Sener and Tecnalia, in collaboration with the University of Padova in Italy and the University Carlos III de Madrid, are pursuing, with **European Space Agency** funding, the development of a commodity-based deorbiting system from low Earth orbit using an electrodynamic tether. In parallel, the team carried out research activities on the Thermionic Bare Tether concept and showed its potential effectiveness in deorbiting objects left in geosynchronous-transfer orbits.

Researchers at the University of Washington have defined two mission concepts to use electrodynamic tethers for passively remediating small pieces of debris in Earth orbit that are untrackable by surface radar. The missions take advantage of the debris' charge buildup that occurs naturally in a space environment. One concept uses the tether's electric field to scatter the debris into a hyperbolic escape orbit, and the second concept uses a vacuum-like mechanism that attracts debris to the surface of the tether.

The Miniature Tether Electrodynamics Experiment, or MiTEE, has been organized into a series of two cubesat missions developing the capability to ultimately deploy a pico-/femtosatellite-tether system (satellites with mass less than 200 grams). The missions will assess the key dynamics and electrodynamic fundamentals of a very short tether system.

The first mission, MiTEE-1, will deploy an end-body on a boom out to a distance of one-half to 1 meter and then apply a bias of about plus-200 volts to the end-body with respect to the cubesat electrical common. The cubesat will also emit an electron beam to close the electrical circuit through the ionosphere. A Langmuir probe onboard will characterize the ionosphere. MiTEE-1 is scheduled to launch in December 2017 as part of NASA's cubesat launch Initiative. ★

▶ **An RS-25 engine** to be used for NASA's Space Launch System undergoes testing at NASA Stennis Space Center in Mississippi.

Reusable vehicles come to forefront

BY DALE ARNEY

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

While NASA continues developing systems for its journey to Mars, industry is pushing forward in key space transportation technologies such as reusability and crew access to space.

SpaceX and Blue Origin are leading the innovation in creating reusable launch vehicles. After SpaceX returned a **Falcon 9** first stage to a landing zone near the launch site in April, it recovered five of the next eight, both at the landing zone and on a drone ship in the Atlantic Ocean. SpaceX test-fired one of the recovered stages in July, and has its first paying customer lined up to use a returned Falcon 9 core projected to launch in late 2016.

To support their plans for large-scale human exploration, Blue Origin and SpaceX revealed the New Glenn and **Mars Colonial Transporter** heavy lift launch vehicles, respectively, set to begin launching in the early 2020s. Meanwhile, DARPA announced phase 2 of its Experimental Spaceplane program to develop technologies needed to achieve "aircraft-like" operability, cost efficiency and reliability in launch vehicles.

In support of its journey to Mars, NASA is qualifying the solid booster and RS-25 main engines for the Space Launch System, or SLS, heavy lift launch vehicle. In June, the booster completed a qualification test and the RS-25 completed a full power test in August. In July, the Government Accountability Office's review of the SLS, Orion crew capsule, and ground operations programs revealed that these systems face challenges to completing their inaugural flight on schedule.

SpaceX and Orbital ATK continued to perform under the first Commercial Resupply Services contract, CRS-1, to deliver cargo to the International Space Station, or ISS. While Orbital has used the Atlas V launch vehicle to deliver cargo in 2016, its **Antares** launch vehicle returned to flight in October with a supply mission to the space station after a static test fire in May. SpaceX returned to flight in December 2015 and has since resumed delivering cargo to the ISS in its Dragon capsule.

NASA in January announced the CRS-2 contract to deliver cargo to ISS in 2019-2024 and added **Sierra Nevada's Dream Chaser** spacecraft to the two incumbents. SpaceX and Boeing continue to test the Crew Dragon and Starliner capsules, respectively, to start delivering crew to ISS starting in 2017 or 2018.

United Launch Alliance, ULA, continues providing access to space for its science, national security, human spaceflight and commercial customers. OSIRIS-REx, Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer, was launched in September and marked ULA's 111th successful launch.

SpaceX and Blue Origin are leading the development of methane rocket engines. Blue Origin's BE-4 component testing continued; the engine is planned for future Blue Origin launch vehicles. **SpaceX's Raptor** is undergoing integrated engine testing. The Air Force announced a series of contracts to promote domestic engine production at ULA, Aerojet Rocketdyne, SpaceX and Orbital ATK.

Internationally, the Indian space agency launched and recovered a subscale shuttle-like vehicle to advance its ability to produce a reusable launch vehicle. Also in 2016, Russia began launching from the Vostochny Cosmodrome, and China inaugurated the Wenchang Satellite Launch Center with the first flight of the Long March 7 launch vehicle.

With the increasing demand for small satellites like cubesats, providers of small launchers are working to be competitive with secondary payload opportunities on larger launch vehicles. Rocket Lab, Firefly Space Systems and Virgin Galactic are all developing less-than-500 kilogram-class launch vehicles that innovate in areas such as engine design, electric propellant pumps and composite structures. ★

Military truck program offers lessons

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.

The first U.S. **Joint Light Combat Vehicle** was delivered to the U. S. Army in September. The JLTV program is an example of higher performance expectations needing integrated vehicle designs that consider the use, potential use and life of the vehicle. The JLTV program survived the "valley of death" between development and procurement by getting a weapon system into the field and using competition and "drive-offs" to determine the winner.

The Army and Marine Corps plan to conduct extensive JLTV tests over the next two years toward an expected initial operational capability for the Army in 2019.

Low-rate initial production of the vehicles, which can be carried internally on C-130s and externally by CH-47 helicopters, began this year following the selection of **Oshkosh Defense** of Wisconsin. In September, the Army exercised a $42 million option following a $243 million order in March. The JLTV will replace thousands of Humvees for the Army and also the Marine Corps.

The JLTV program has been a story of twists and turns. The program was formally begun in 2006, with the word "Joint" indicating that the vehicles will be destined for the Army and Marines. The program was initially envisioned as developing a family of light tactical vehicles to replace the **Humvee**, which first saw use in 1985. Though the Humvee was effective and met its design criteria, operations in the Middle East led to a need for additional ballistic armor and blast protection. The first two years of JLTV focused on developing requirements based on that experience. Given the history of the canceled **Future Combat Systems** program, the expectations for the JLTV were pared back.

In 2008, the Army released a request for proposals for technology development. Each funded team built four vehicles over a 15-month time frame and these vehicles were tested for 12 months. Contracts of approximately $40 million each were awarded to three teams: BAE Systems Land and Armaments (formerly United Defense, the maker of the Bradley vehicle) joined forces with the truck company NAVISTAR of Illinois; General Dynamics Land Systems and Humvee-maker AM General created a team called General Tactical Vehicles; Lockheed Martin and BAE Systems Mobility and Protection Systems (formerly Armor Holdings), joined up with ALCOA, and JWF Defense Systems of Pennsylvania.

In 2012, the RFP was released for the engineering and manufacturing development or EMD phase. Only one of the 2008 selectees won an EMD award. Each of the three winners was given approximately $60 million to build 22 prototypes toward meeting a target unit cost of $250,000 for the production vehicles. The three awards went to Lockheed Martin (one of the 2008 selectees), AM General and Oshkosh.

Each team brought strengths. What may have been the decisive strength were the wins by Oshkosh for the **Mine-resistance Ambush-protected All-Terrain Vehicle**, or M-ATV, in 2009. Oshkosh hit a production rate of 1,000 vehicles per month just six months after that contract award, and the M-ATV saw extensive use in Afghanistan.

The final JLTV award went to Oshkosh in 2015 to build 16,901 vehicles for $6.75 billion, a cost slightly less than $400,000 per vehicle. The company's entry, which it called the L-ATV for **Light Combat Tactical ATV**, has extensive maneuverability and survivability capabilities. There are now two variants, one with a crew of two and one with a crew of four, with various cargo capabilities. It is expected that in the long run the total procurement for this general purpose vehicle will be over 50,000 vehicles.

An interesting lesson from this procurement is that the ultimate winner continued with its own internal funding when it failed to obtain the first round of development awards, but was able to win an EMD award. This shows that internal funding can overcome development contract losses for weapon systems that are not extremely expensive. The JLTV will be the next general purpose ground vehicle, probably for another 30 plus years, as was the Humvee, and before it, the Jeep. ★

▼ **The U.S. Army and the Marine Corps** plan to perform extensive tests on the Joint Light Combat Vehicle over the next two years toward operational capability in 2019.

Oshkosh Defense

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Calendar

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

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2017			
7 Jan	Space Standards and Architecture Workshop	Grapevine, TX	
7–8 Jan	Introduction to Shock-Wave/Boundary-Layer Interactions Course	Grapevine, TX	
7–8 Jan	Liquid Atomization, Spray, and Fuel Injection in Aircraft Gas Turbine Engines Course	Grapevine, TX	
7–8 Jan	Six-Degrees-of-Freedom Modeling of Missile and Aircraft Simulations Course	Grapevine, TX	
7–8 Jan	2nd AIAA Sonic Boom Prediction Workshop	Grapevine, TX	
8 Jan	Hypersonics Test Course	Grapevine, TX	
8 Jan	7 Axioms for Good Engineering Workshop	Grapevine, TX	
9 Jan	2017 Associate Fellows Recognition Ceremony and Dinner	Grapevine, TX	
9–13 Jan	AIAA SciTech Forum (AIAA Science and Technology Forum and Exposition) Featuring: – 25th AIAA/AHS Adaptive Structures Conference – 55th 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 – 19th AIAA Non-Deterministic Approaches Conference – 58th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference – 10th Symposium on Space Resource Utilization – 4th AIAA Spacecraft Structures Conference – 35th Wind Energy Symposium	Grapevine, TX	6 Jun 16
22–26 Jan†	97th American Meteorological Society Annual Meeting	Seattle, WA (Contact: https://annual.ametsoc.org/2017/)	
23–26 Jan†	63rd Annual Reliabiltiy & Maintainability Symposium (RAMS 2017)	Orlando, FL (http://rams.org/)	
5–9 Feb†	27th AAS/AIAA Space Flight Mechanics Meeting	San Antonio, TX (Contact: www.space-flight.org/docs/2017_winter/2017_winter.html)	7 Oct 16
4–11 Mar†	IEEE Aerospace Conference	Big Sky, MT (Contact: www.aeroconf.org)	
6–9 Mar†	21st AIAA International Space Planes and Hypersonic Systems and Technology Conference (Hypersonics 2017)	Xiamen, China	22 Sep 16
29 Mar	AIAA Congressional Visits Day (CVD)	Washington, DC (http://www.aiaa.org/CVD/)	
18–20 Apr†	17th Integrated Communications and Surveillance (ICNS) Conference	Herndon, VA (Contact: Denise Ponchak, 216.433.3465, denise.s.ponchak@nasa.gov, http://i-cns.org)	
25–27 Apr	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	4 Oct 16
25–27 Apr†	EuroGNC 2017, 4th CEAS Specialist Conference on Guidance, Navigation, and Control	Warsaw, Poland (Contact: robert.glebocki@mel.pw.edu.pl; http://www.ceas-gnc.eu/)	
2 May	2017 Fellows Dinner	Crystal City, VA	
3 May	Aerospace Spotlight Awards Gala	Washington, DC	

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

AIAA Continuing Education offerings

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
8–11 May†	AUVSI/AIAA Workshop on Civilian Applications of Unmanned Aircraft Systems	Dallas, TX (www.xponential.org/auvsi2016/public/enter.aspx)	
15–19 May†	2017 IAA Planetary Defense Conference	Tokyo, Japan (Contact: http://pdc.iaaweb.org)	
25–29 May†	International Space Development Conference	St. Louis, MO (Contact: ISDC.nss.org/2017)	
29–31 May†	24th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (Contact: Ms. M. V. Grishina, icins@eprib.ru, www.elektropribor.spb.ru)	
3–4 Jun	3rd AIAA CFD High Lift Prediction Workshop	Denver, CO	
3–4 Jun	1st AIAA Geometry and Mesh Generation Workshop	Denver, CO	
5–9 Jun	AIAA AVIATION Forum (AIAA Aviation and Aeronautics Forum and Exposition) Featuring: – 24th AIAA Aerodynamic Decelerator Systems Technology Conference – 33rd AIAA Aerodynamic Measurement Technology and Ground Testing Conference – 35th AIAA Applied Aerodynamics Conference – AIAA Atmospheric Flight Mechanics Conference – 9th AIAA Atmospheric and Space Environments Conference – 17th AIAA Aviation Technology, Integration, and Operations Conference – AIAA Flight Testing Conference – 47th AIAA Fluid Dynamics Conference – 18th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference – AIAA Modeling and Simulation Technologies Conference – 48th Plasmadynamics and Lasers Conference – AIAA Balloon Systems Conference – 23rd AIAA Lighter-Than-Air Systems Technology Conference – 23rd AIAA/CEAS Aeroacoustics Conference – 8th AIAA Theoretical Fluid Mechanics Conference – AIAA Complex Aerospace Systems Exchange – 23rd AIAA Computational Fluid Dynamics Conference – 47th Thermophysics Conference	Denver, CO	27 Oct 16
5–6 Jun	Cybersecurity Symposium at AIAA AVIATION Forum	Denver, CO	
6–7 Jun	DEMAND for UNMANNED at AIAA AVIATION Forum	Denver, CO	
6–9 Jun†	8th International Conference on Recent Advances in Space Technologies (RAST 2017)	Istanbul, Turkey (Contact: www.rast.org.tr)	
7–9 Jun	Electric Flight Workshop at AIAA AVIATION Forum	Denver, CO	
19–21 Jun†	9th International Workshop on Satellite Constellations and Formation Flying	Boulder, CO (Contact: http://ccar.colorado.edu/iwscff2017)	
10–12 Jul	AIAA Propulsion and Energy Forum (AIAA Propulsion and Energy Forum and Exposition) Featuring: – 53rd AIAA/SAE/ASEE Joint Propulsion Conference – 15th International Energy Conversion Engineering Conference	Atlanta, GA	4 Jan 17
20–24 Aug†	2017 AAS/AIAA Astrodynamics Specialist Conference	Stevenson, WA	24 Apr 17
12–14 Sep	AIAA SPACE Forum (AIAA Space and Astronautics Forum and Exposition)	Orlando, FL	21 Feb 17
13–16 Sep†	21st Workshop of the Aeroacoustics Specialists Committee of the Council of European Aerospace Societies (CEAS)	Dublin, Ireland	
25–29 Sep†	68th International Astronautical Congress	Adelaide, Australia	28 Feb 17

News

Making a Difference by Raising the Profile of Aerospace in Washington

AIAA's 20th annual Congressional Visits Day (CVD) program will be held Wednesday, 29 March 2017. CVD is an exciting and eye-opening event that brings together members from all over the country for a day of advocacy on Capitol Hill. Participants meet with their elected officials to promote the Institute's key issues and raise awareness of the long-term value that science, engineering, and technology bring to the nation.

A large majority of the participants from this past year's event were students and young professionals – groups that are essential to helping advance and promote our community's public policy objectives.

The following are testimonials from three past CVD participants:

DAVID FOX

MECHANICAL ENGINEER, ORBITAL ATK

When I joined AIAA, I never thought I'd be visiting Congress on its behalf. I had heard about Congressional Visits Day through AIAA communications and was encouraged by some of our local members to attend. I was interested in voicing some concerns of the aerospace community to our congressional representatives, but, as an engineer, I was also very excited to see the inner workings of Congress and gain some additional insight into its operations firsthand.

I had no idea what to expect as we approached our first office – would the staff members care about our issues and would they understand the issues? The first meeting was eye opening to me, as I learned that the congressional offices are more than willing to hear from their constituents and have staff members who are well versed in a multitude of topics. Some congressional members and their staff were quite knowledgeable about the aerospace industry and were even advocates for its success, while others were not, so the discussions at each office varied to relay the important main points to those less informed or provide additional details to those seeking more information.

As I reflect back on CVD, I can't help but recall how friendly and welcoming the congressional staff members were during our visit. Regardless of their stance on aerospace industry issues, they were willing to dedicate some of their time to hear our thoughts. If you have even a small desire to attend CVD in the future, I encourage you to give it a shot and approach it with an open mind.

KAYLEIGH GORDON

AEROSPACE ENGINEERING STUDENT, OHIO STATE UNIVERSITY

Before my first CVD I was unfamiliar with the policy issues that influenced the aerospace community, but the event helped me discover aerospace policy and learn how policies are formed and implemented through advocacy and legislation. Through this firsthand experience with Congress, I gained insight into how the legislative process works and exposure to how constituent feedback affects the formulation of future policies.

My experiences at CVD inspired me to become more engaged with state-level policy outreach where I have applied my knowledge of the policy process that I gained from CVD. To continue exploring aerospace policy I have attended local meetings of the Ohio Aerospace and Aviation Technology Committee because I was interested in learning about local aerospace policy and how it is influenced by national policies.

CVD is also a great opportunity to work with other people who are passionate about aerospace. We all come together with the common objective of advocating for the policy issues that are relevant to our community. Interaction with fellow students, professionals, and lawmakers from around Ohio is a highlight of the event for me every year.

I believe it's important for students to participate in CVD because we are the future of the sector. It is crucial that we understand current aerospace policy issues so we can work to improve the community. I will continue to participate because it's important to me to dedicate my time to help our industry develop and grow.

BRIAN MUNGUIA

AEROSPACE ENGINEERING STUDENT, STANFORD UNIVERSITY

I have participated in CVD the past three years, first in 2014 with Ohio State University and more recently with Stanford University. The CVD program is definitely one of the most educational experiences that I've had as an engineering student and I only have positive things to say about it. With the way that the media portrays politics, it's easy to see why people get so disheartened with all the gridlock and the slow progress of STEM initiatives. After attending CVD and speaking with members of Congress and aides from both Ohio and California, though, something that I've realized is that there are people on Capitol Hill who care about what we have to say, and that we really do have a voice in our government.

To me, the real value of CVD is that it's educational for everybody involved. Many engineers don't experience the policy side of engineering, and CVD can teach us how difficult of a job it can be. Similarly, we can teach legislators and their aides what's important to our fields, why our fields are so important, and inform them on how their decisions impact us. Sharing this learning experience with new people every year is why I look forward to CVD.

As these alumni have shared, CVD offers AIAA student and professional members an experience that opens their eyes to the inner workings of our legislative process. It also is an opportunity to be an advocate for the aerospace community and enhance your career development. We hope you will participate in CVD 2017. See you in Washington, DC, in March!

To learn more about the CVD program and register for the 2017 event, visit www.aiaa.org/cvd.

Emeritus Ceremony For Dr. Arloe W. Mayne

by Ken Philippart

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1 Dr. Mayne with AIAA student members after the event.

2 Dr. Mayne regales the crowd with flying stories.

3 Sheree Gay presents the Section gift to Dr. Mayne

4 Section Chair Brandon Stiltner presents Dr. Mayne with his Emeritus Certificate.

Images courtesy of Lisa Philippart, Wes Mayne and Alan Lowrey

The AIAA Greater Huntsville Section honored Dr. Arloe W. Mayne for his 50-plus years of service during an Emeritus Ceremony on August 26, 2016. Dr. Mayne has had a distinguished career in the aerospace industry. He holds a Bachelor of Science degree in Mechanical Engineering and a Master of Science degree from the University of Kentucky in Lexington. He also earned a Doctorate in Mechanical Engineering from the University of Tennessee Space Institute. His career included working at the Martin Company in Orlando, FL; at the Arnold Engineering Development Center (AEDC) near Tullahoma, TN; and at TRW in Huntsville, AL, and Greenbelt, MD. He was a systems engineer with TRW, and worked in Computational Fluid Dynamics at AEDC.

Dr. Mayne's involvement in AIAA spans six decades. In 1960, he joined the Institute of the Aerospace Sciences (IAS) as a student member at the University of Kentucky and became a founding member of AIAA when IAS and the American Rocket Society merged in 1963. He is an AIAA Associate Fellow, and has served in various positions with the Greater Huntsville Section, including Section Chair. He was a member of the AIAA Fluid Dynamics Technical Committee, and authored several papers in that field. As part of the Section's Centennial of Flight activities, he researched and developed plans for Robert Goddard's first successful liquid-fueled rocket. He was awarded an AIAA Special Service Citation for this work. In 2014, Dr. Mayne received AIAA's Sustained Service Award for service to the Institute.

The ceremony was held at Huntsville Executive Airport, where Dr. Mayne first learned to fly and where he still flies today. Over 40 people packed the airport's executive conference room conference room to honor Dr. Mayne's years of service. The event opened with remarks from Emcee Ken Philippart and Section Chair Brandon Stiltner. Mr. Stiltner presented Dr. Mayne with his Certificate of Emeritus. Dr. Mayne has served on the Greater Huntsville Section Council for almost 20 years, including as Section Chair and his current position as Webmaster. After Dr. Mayne's wife, Linda, pinned his Emeritus Pin on his lapel, Section Vice Chair Dr. Naveen Vetcha presented him with the Greater Huntsville Section coin to recognize his career of excellence. Six Young Professionals then presented Dr. Mayne with a print of the poem High Flight superimposed over a glorious sunset. Finally, former Council member Mrs. Sheree Gay, presented the Section's gift to Arloe, an enamel sign of a Cessna-172 bearing the tail number of the aircraft that Arloe flies regularly and that was sitting on the ramp outside the conference room.

Dr. Mayne told several interesting stories about his flying and AIAA experiences. He concluded by presenting past Section Chair Ken Philippart with an AIAA Section Chair 25-year pin that Mayne had received many years before. The evening concluded with group photos including pictures of Dr. Mayne with the student members, to illustrate the continuation of AIAA across generations. Dr. Mayne's ceremony was Greater Huntsville's second Emeritus ceremony and part of the Section's renewed efforts to publicly honor its long-serving, faithful members while passing on the Section's proud legacy to younger generations.

Diversity Working Group Releases Diversity and Inclusion Plan

Recognizing the importance of a representative and inclusive workforce to the aerospace community, AIAA established a Diversity Working Group (DWG) in 2015. Its mandate was to explore opportunities to better promote and encourage diversity and inclusion throughout the aerospace workforce and the Institute.

The group's ongoing work has produced AIAA's first-ever Diversity and Inclusion Plan. The plan's recommendations for near-, mid-, and long-term actions lay out concrete steps that the Institute and our members can take to help support and retain professionals once they have entered the workforce, build a culture of inclusion and diversity throughout our Institute and workforce, and recognize individual and employer efforts to promote diversity and inclusion. As a "living document" the plan will grow as necessary to accommodate new needs, priorities, and the realities of an ever-changing workforce.

The DWG members will work with fellow Institute leaders to implement the plan's goals to help create an environment where input is contributed across the breadth of the team, where all ideas are brought forward and vigorously discussed and debated, and that is truly supportive of the needs and voices of all individuals who wish to use their time and talents to shape the future of aerospace. To read the Diversity and Inclusion Plan, learn more about the DWG, and to get involved, please visit: aiaa.org/diversity.

Nominations Sought for NACA and NASA Langley Hall of Honor

The Langley Alumni Association and the NASA Langley Research Center request nominations of past distinguished NACA Langley Memorial Aeronautical Laboratory and NASA Langley Research Center employees, both civil service and contractors, for the NACA and NASA Langley Hall of Honor Class of 2017. Nominees must have had exemplary careers and made significant and enduring contributions in or in support of revolutionary scientific understanding and technological progress in line with the goals of NACA or NASA Langley, and the nation.

More information about nominee eligibility, and the nomination form are available at the Langley Alumni Association website at www.larcalumni.org/the-langley-research-center-naca-and-nasa-hall-of-honor/. Nominations are due by noon, 2 January 2017, and must be emailed to info@LaRCAlumni.org. Please e-mail any questions regarding your nomination to info@LaRCAlumni.org.

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Distinguished Lecturer Trip to Australia

AIAA Associate Fellow Dr. Randii Wessen visited Australia from 15–28 August, to discuss the robotic planetary missions currently in operations at the Jet Propulsion Laboratory and those planned for the upcoming decades. The trip was sponsored by AIAA as part of the Distinguished Lecturer Program and was organized by the AIAA Adelaide Section with help from AIAA members around Australia. The itinerary included five public talks (Sydney – 250 attendees, Adelaide – 200, Melbourne – 250, Canberra – 350 and Brisbane – 350), one private lecture and tour (DSTG Melbourne – 100), three STEM outreach events (Adelaide, Sydney, and Canberra), two AIAA member-only events (Adelaide and Sydney) and two radio interviews (Radio National Science Program and Triple J Hack). Dr. Wessen was an engaging speaker and appealed to audience members of all ages. Overall the visit was extremely successful and was of enormous benefit to the Australian AIAA members and general public.

1 **Dr. Wessen** at the Adelaide AIAA member-only event.

2 **Dr. Wessen** presenting in Melbourne.

2017 Space Systems AIAA Essay Contest

The AIAA Space Systems Technical Committee invites you to participate in a National Annual Essay Contest for students in 7th and 8th Grade through AIAA Sections.

THEME: Choose one of the aspects of the Juno spacecraft listed on the webpage below. Describe how it works and why it helps discovery at Jupiter (https://www.missionjuno.swri.edu/spacecraft/juno-spacecraft).

REQUIREMENTS:
Double-spaced, typewritten (size 12 font) essay, in 1,000 words or less
- Student name, teacher name, grade, and school name must be written in the top right-hand corner of the essay
- Include student and teacher name, phone, email, and mailing address for notification and awards

JUDGING CRITERIA:
- Originality of ideas presented
- Soundness of logic used to develop ideas
- Realism of ideas presented
- Quality of composition and clarity of expression

(Note: All decisions by the judges are final)

PRIZES: At each grade level:
- Certificate of recognition
- $100 award + $250 for their science classroom
- Recognition and essays published by AIAA at a national level

ELIGIBILITY: Any seventh or eighth grader (or equivalent). Please contact your local section officers (http://www.aiaa.org/RegionSectionMap.aspx) to confirm that they will be running the contest and accepting entries. Entries accepted by “at-large” students through Jeff Puschell, jjpuschell@raytheon.com.

DEADLINE: Ask your local AIAA section officers for deadline and where to send entries. Local winners and their teachers will be notified by April. National winners and their teachers will be notified by May.

QUESTIONS: Email Anthony Shao and Erica Rodgers (ant.shao@gmail.com, erica.rodgers@nasa.gov)

The winner of the 2016 AIAA Joseph Freitag Sr. Award was Thomas Gaenzle, Automotive Mechatronics Engineer. A reception was held to commemorate the 100th anniversary of Daimler Chrysler Ausbildung and Training School (which Mr. Freitag Sr. graduated from in 1922). This is the 10th year this award has been given.

Award Presented at ICSSC

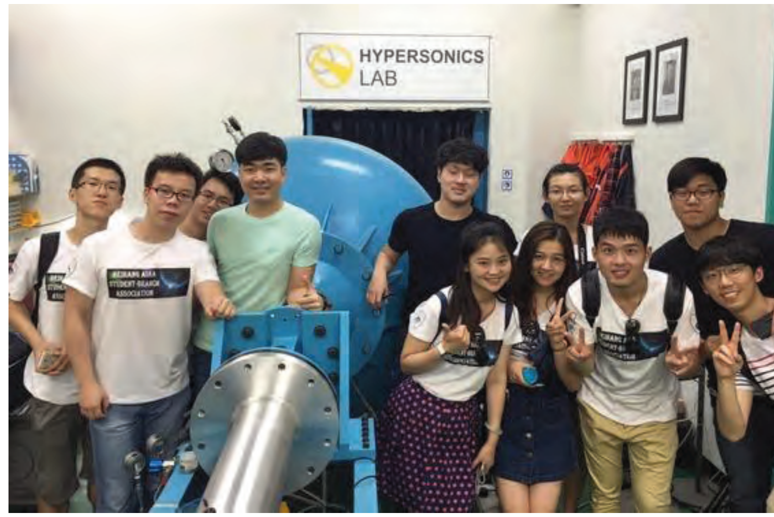
The 2016 AIAA Aerospace Communications Award was recently presented to Christopher Hoeber, Satellite Industry Consultant, during the 34th AIAA International Communications Satellite Systems Conference (ICSSC) at NASA Glenn Research Center. Hoeber was recognized for communications satellite industry and engineering leadership and for advancing technologies ranging from electronic propulsion to reliable high power communications satellites.

Beihang University's AIAA Student Branch Visited Korea in August

In August, members of Beihang University's AIAA Student Branch (BASA) visited Korea and toured several universities to see their science programs and labs. Members of the AIAA student branch at Korea Advanced Institute of Science and Technology (KAIST) gave a brief introduction of the school and showed key projects from the School of Aerospace Engineering and activities held by KAIST-AIAA. The creativity of the students and the lively academic atmosphere earned applause from the Beihang students. Jing Pu, chairman of Beihang AIAA Student Branch, also shared some information about the School of Aeronautical Science and Engineering at Beihang. Students were able to tour KAIST's base of aeromodeling and the Photoelectric Structure Integration laboratory, the Space System and Control Lab, and the Hypersonics Lab, where they were given a detailed introduction to the equipment that produces hypersonic airflow.

The school's director, Professor Jae-Hung Jay Han, and Professor Jiyun Lee from KAIST-AIAA welcomed the students. Professor Han said that he hoped that students from the two universities continue to share their ideas and knowledge through conversations and lectures to build a bridge between the two schools. Professor Lee spoke of KAIST-AIAA's activities, and shared other advice with the students. BASA presented Beihang University-featured fans and some delicate postcards as gifts to their hosts.

The students also visited the Aerospace Museum on Jeju island, and the national Palace Museum (Gyeongbok Palace).



BASA students visiting the KAIST Hypersonics Lab

Obituaries

AIAA Senior Member Hoh Died in October 2015

Siegfried R. Hoh died on 14 October 2015. He was 100 years old. He had been a member of AIAA for over 50 years, since 1961.

Mr. Hoh study began his career in Germany, and was part of the development team for the V-2 rocket. Because he was a physicist, he was assigned to the German Rocket Development Center in Peenemunde, Germany. After the British Royal Air Force conducted a surprise attack on the facility, Hoh and other scientists were moved to Bavaria.

After the war ended Hoh was one of the scientists brought to the United States as part of Operation Paperclip. Initially the scientists sorted through captured documents about the V-2 rocket. But a few months after arriving in the United States, Hoh was assigned to work with the Air Force on wind tunnel technology. His name can be found in the "Objective List of German and Austrian Scientists" from January 1947, where it states that he was at Wright Field, OH.

Mr. Hoh later worked with ITT in New Jersey from 1958 to 1965. In 1965, he moved to Florida to help calibrate instruments aboard the Apollo spacecraft. He received a letter from former NASA Kennedy Space Center Director Kurt Debus thanking him for his contributions to the Apollo program. Mr. Hoh retired in 1975.

In 2003, Mr. Hoh travelled back to Peenemunde to see the museum there. He always marveled how quickly progress was made on rockets and spacecraft between World War II and the Apollo era.

AIAA Senior Member Sebesta Died In June

Henry R. Sebesta died on 30 June 2016.

Dr. Sebesta went to the University of Texas in Austin where he earned B.S., M.S., and Ph.D. degrees in Mechanical Engineering. He joined the National Guard in high school, serving two terms.

In 1967, Dr. Sebesta joined the faculty of the Oklahoma State University Engineering Department. He was later appointed as the chairman of the Mechanical Engineering Department at the University of Texas, Arlington. In 1979, he left academia and joined the aerospace and technology firm Applied Technology Associates, Inc. (ATA) in Albuquerque, NM, where he served as president/CEO and, ultimately, as chief scientist. Under Dr. Sebesta's leadership, ATA was awarded hundreds of millions of dollars in contracts from U.S. government agencies including the Department of Defense, the Department of Transportation, and NASA and partnered with private sector companies such as Boeing, Lockheed Martin, and Ball Aerospace. He retired from ATA in 2012.

AIAA Senior Member Stanley Died in October

Norman Stanley died on 22 October 2016, at the age of 100.

He began working at Algin Corporation in his twenties. An amateur chemist, the job allowed Mr. Stanley the chance to be a real chemist. He had read about a material called carrageenan, and he convinced his boss he should be allowed to find a way to extract it from seaweed. He was successful and was awarded a patent for it along with a payment from the company for $1. Carrageenan proved to be a very popular product for the company and they changed their name from The Algin Corp to Marine Colloids to cover their expanded product line. Mr. Stanley continued to enjoy his work in the research lab for the next 55 years.

His many interests including being a Hall of Fame member of the "First Fandom" group that started the science fiction craze back in the 1930s. He was a member of the British Interplanetary Society as well as AIAA.

AIAA Senior Member Jimenez Died in October

Hernando Jimenez passed away on 23 October 2016, at the age of 36.

Dr. Jimenez was a three-time graduate of the Georgia Institute of Technology, earning his Bachelor of Science (2003), Master of Science (2006), and Doctorate of Philosophy (2009) in Aerospace Engineering. A Research Engineer II working in Georgia Tech's Aerospace Systems Design Laboratory, he led a number of major research projects in the areas of systems analysis of UAS, environmentally responsible aviation, and next-generation technologies.

His many achievements include the 2010 Tower Award, the 2010 ASDL service award, the 2007–2008 Sam Nunn fellowship, chapters in two books and multiple research publications contributing to civil aviation. Dr. Jimenez served as the chair of the AIAA Aircraft Design Technical Committee from 2014 to 2016. He also served on the AIAA Green Engineering Program Committee for a short time. He was also a 2018 AIAA AVIATION Forum Deputy Technical Chair for the A/C and Atmospheric Systems Group.

AIAA Associate Fellows Myers Died in October

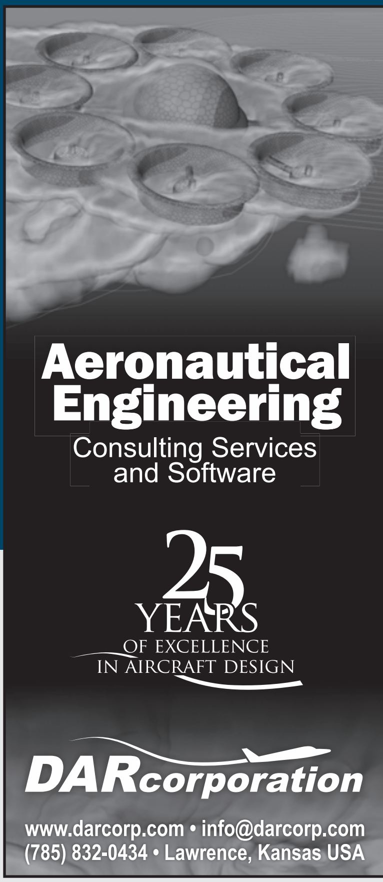
Michael K. Myers died on 29 October 2016. He was 77 years old.

Professor Myers received a B.A. from Willamette University (1962) and continued his education at Columbia University, where he attained a B.S. (1962), M.S. (1963), and Ph.D. (1966).

After serving as an Associate Professor at Columbia, he helped establish the Joint Institute for Advancement of Flight Sciences (JIAFS) at George Washington University (GWU) in 1973. Over the next 30 years, as director of the Aeroacoustics Program at JIAFS, Professor Myers published dozens of technical papers, educated hundreds of students, and served in a variety of professional positions. His seminal work came in 1980, when he published "On the Acoustic Boundary Condition in the Presence of Flow" in the *Journal of Sound and Vibration*. The work's impact was indelible: the Myers Boundary Condition is now well established in acoustics.

Professor Myers won numerous awards and honors throughout his career, beginning with the prestigious Illig Medal from Columbia University in 1962. As well as being an AIAA Associate Fellow, he belonged to five academic honor societies, was a member of the Acoustical Society of America, and served as chairman of the Department of Mechanical and Aerospace Engineering at GWU from 1999 to 2008, retiring as Professor Emeritus of Engineering and Applied Sciences.

AIAA FOUNDATION
Advancing Aerospace



DEPARTMENT OF AEROSPACE ENGINEERING - Open Rank Faculty Search

College of Engineering

University of Illinois at Urbana-Champaign

The Department of Aerospace Engineering at the University of Illinois at Urbana-Champaign seeks highly qualified candidates for multiple faculty positions in all areas of aerospace engineering, with emphasis on the areas of orbital mechanics, space systems, multi-functional composites, and additive manufacturing. Preference will be given to qualified candidates working in emerging areas of aerospace engineering whose scholarly activities have high impact. Please visit **http://jobs.illinois.edu** to view the complete position announcement and application instructions. Full consideration will be given to applications received by **December 16, 2016**. Applications received after that date may be considered until the positions are filled.

The University of Illinois conducts criminal background checks on all job candidates upon acceptance of a contingent offer.

Illinois is an EEO Employer/Vet/Disabled - www.inclusiveillinois.illinois.edu and committed to a family-friendly environment (http://provost.illinois.edu/worklife/index.html).

AEROSPACE ENGINEERING
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

THE OHIO STATE UNIVERSITY
COLLEGE OF ENGINEERING

Faculty Position in Unmanned Aircraft Systems

Department of Mechanical and Aerospace Engineering

DESCRIPTION

The Department of Mechanical and Aerospace Engineering at The Ohio State University invites applications for a tenure-track faculty position in the broad area of Unmanned Aircraft Systems (UAS) at the rank of Assistant Professor. Research advances in the fundamental areas of aerospace engineering are critical for future development of UAS and their safe & efficient integration into the national airspace. Research areas of interest within the broad topic of UAS include, but are not limited to: guidance, navigation, and control of autonomous vehicles; distributed control, sensing, and navigation; artificial intelligence; remote sensing; state estimation; intelligent sensor fusion; integrated propulsion; and biologically inspired UAS/MAVs.

QUALIFICATIONS

Candidates with demonstrated technical expertise, creativity, and leadership are sought. A particular emphasis will be placed on candidates at the frontier of research and education. A doctoral degree is required in Aerospace or Mechanical Engineering, or in a related field appropriate to the scope of the position. Candidates who can successfully work in a collaborative environment are sought. Applications from underrepresented minority groups are particularly encouraged. The anticipated start date is August 2017. Screening of applicants will begin immediately and will continue until the position is filled.

ABOUT OHIO STATE

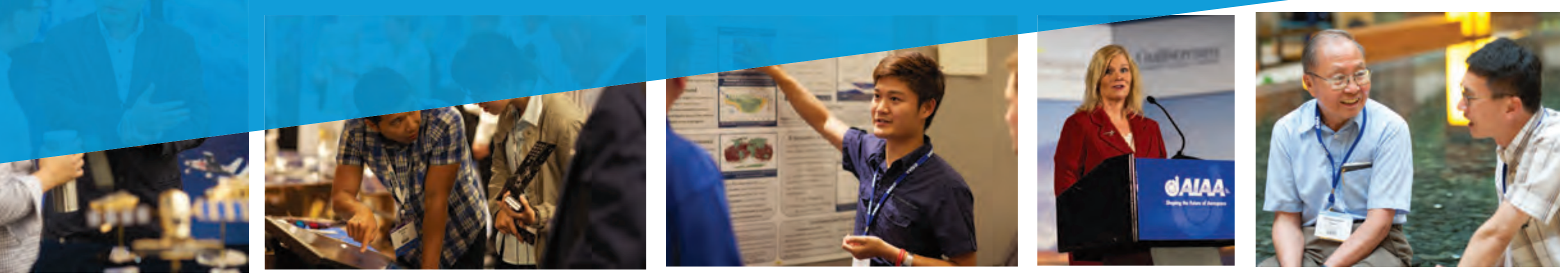
This position will be affiliated with the Aerospace Research Center (ARC), http://arc.osu.edu/uas, an interdisciplinary research center within the OSU College of Engineering. The Center supports a robust collaborative environment, facilitating connections among approximately 40 faculty from across the University who are actively engaged in UAS research. Faculty expertise spans the areas of positioning, navigation, and timing (PNT); robust flight in wind gusts; UAV icing; vision-based localization and object tracking; precision agriculture; law; policy; spectrum; communications and control links; autonomous systems; human factors; data analytics; flight testing; vehicle state estimation and control; and remote sensing. The Center is also a leading member of the FAA's Center of Excellence for Integrating Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS), which is a 10-year center started in 2015 to study the complex problems associated with safe and efficient integration of UAS in the NAS. The successful candidate is invited to engage with and contribute to this vibrant community of scholars working in the domain of UAS-related research.

HOW TO APPLY

Applications for this position will be accepted until the position is filled. Applications should include a cover letter, CV, research and teaching statements of 2-3 pages each, and contact information of at least four references. Application materials should be submitted as a single PDF to https://mae.osu.edu/employment/faculty-position-UAS.

To build a diverse workforce, Ohio State encourages applications from individuals with disabilities, minorities, veterans, and women. Ohio State is an EEO/AA Employer. The Ohio State University is committed to establishing a culturally and intellectually diverse environment, encouraging all members of our learning community to reach their full potential. Columbus is a thriving highly rated metropolitan community and we are responsive to dual-career families and strongly promote work-life balance to support our community members through a suite of institutionalized policies. We are an NSF ADVANCE Institution and a member of the Ohio/Western Pennsylvania/West Virginia Higher Education Recruitment Consortium. For more information about the Department of Mechanical and Aerospace Engineering at OSU, please visit http://mae.osu.edu/.

Mark Your 2017 Calendars!



AIAA Forums and Expositions

AIAA SciTech Forum

9–13 January 2017 • Grapevine, Texas

Aerospace was born a disruptive technology. Discover the disruptive business models, policy issues, technology developments, and other factors driving today's disruptive environment.

RegisterToday!
aiaa-scitech.org

AIAA DEFENSE Forum

25–27 April 2017 • Laurel, Maryland

Innovative concepts, technologies, and collaboration will drive revolutionary improvement in warfighting capabilities. This SECRET/U.S. ONLY forum is the place for classified and unclassified discussions.

Register Today
aiaa-defense.org

AIAA AVIATION Forum

5–9 June 2017 • Denver, Colorado

With 18 individual technical conferences, a green aviation day, a new electric flight workshop, and the 2nd DEMAND for UNMANNED symposium, AIAA AVIATION is more exciting and expansive then ever.

Get Alerts
aiaa-aviation.org

AIAA Propulsion and Energy Forum

10–12 July 2017 • Atlanta, Georgia

Propulsion and energy systems are at the very heart of aerospace. Discover game-changing advancements.

Submit Your Abstracts
aiaa-propulsionenergy.org

AIAA SPACE Forum

12–14 September 2017 • Orlando, Florida

We're moving to Florida in 2017 because virtually every major space organization—government and industry—has a presence in the area.

Submit Your Abstracts
aiaa-space.org

"Having the opportunity to come face-to-face with the best and brightest is critical to the continued success of our corporation."

—**John O'Leary,** *Vice President and General Manager Airbus Americas Engineering*

"You have the chance to affect things. Some ideas that I've seen have started in hallway conversations at AIAA forums… have gone far beyond anything I would ever believe."

—**Rich Wahls**, *Strategic Technical Advisor, Advanced Air Vehicles Program, NASA Aeronautics Research Mission Directorate*

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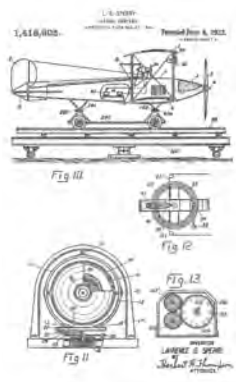

Dec. 22 Lawrence Sperry, son of the famous inventor Elmer Sperry, files a U.S. patent for an "Aerial Torpedo," a precursor to the guided missile. The patent, No. 1,418,605, is granted on June 6, 1922. Lawrence incorporates modifications of his father's gyro stabilizers for ships to produce an automatic stabilizer for an unmanned aircraft. Also featured is a revolution counter that automatically counts the revolutions of the aircraft's propeller, then cuts off the engine so the plane that is carrying high explosives will dive toward its target. Lawrence Sperry, with his father's help, begins experimenting with the Aerial Torpedo this year. In some tests, Lawrence, who is also a famed pilot, rides in the craft to monitor its behavior in flight and sustains several crashes. William Davenport, "Gyro!" pp. 190, 215-218.

1941

Dec. 2 Pan American's Pacific Clipper, a Boeing 314, departs from San Francisco for the first complete around-the-world tour by a commercial plane, arriving in New York on Jan. 6 after a 50,700-kilometer flight. Capt. Robert Ford is the pilot. R.E.G. Davies, Airlines of the United States Since 1914, p. 267.

Dec. 7 Without declaring war, 354 Japanese Navy aircraft from six fleet carriers bomb Hawaii's Pearl Harbor in two waves. This causes extensive damage to the U.S. Pacific Fleet, disabling all eight of the fleet's battleships, three cruisers and three destroyers. More than 2,000 people are killed. However, four aircraft carriers stationed at Pearl are at sea on the day of the attack. Key dockyard cranes and other machinery are also saved, permitting rapid repair of the damaged ships and facilities. The attack also galvanizes public support for President Franklin Roosevelt as he calls for war against Japan. Roger Bilstein, Flight in America 1900-1983, pp. 132-133.

Dec. 8 In response to the attack on Pearl Harbor, Roosevelt declares war on Japan. Roger Bilstein, Flight in America 1900-1983, pp. 132-133.

Dec. 8 Twelve hours after they bomb Pearl Harbor, Japanese planes attack Clark Field in the Philippines, using 108 bombers and 84 Zero fighters. Here, too, the Americans are caught off guard, and the bombing inflicts great damage, destroying 18 B-17s, 56 P-40s and P-35s, and 26 other aircraft. The Japanese lose only seven Zeros. E.B. Santos, Trails in the Philippine Skies, pp. 275-276.

Dec. 10 In the first U.S. offensive against Japan, B-17 Flying Fortress bombers are sent against Japanese shipping. On the same day, aircraft from the aircraft carrier USS Enterprise destroy their first Japanese ship, a submarine that scouted the Hawaiian area in preparation for the attack on Pearl Harbor. United States Naval Aviation 1910-60, p. 90.

Dec. 11 Following Japan's attack against the U.S. Pacific Fleet in Pearl Harbor, Hawaii, both Germany and Italy declare war on the United States. Roger Bilstein, Flight in America 1900-1983, pp. 132-133.

Dec. 18 The Army Air Force's Lt. Boyd "Buzz" Wagner reportedly destroys his fifth Japanese aircraft over the Philippines, making him the first U.S. ace of World War II. Howard Mingos, "American Heroes of the War in the Air," p. 41.

Dec. 18 Reaction Motors Inc., or RMI, is founded at Pompton Lakes, N.J., as the first U.S. liquid-propelled rocket company. It is founded by four members of the American Rocket Society: Lovell Lawrence Jr., who serves as its first President; John Shesta, James Wyld and H. Franklin Pierce. The company is based on the regeneratively cooled rocket motor of Wyld that was successfully tested several times on ARS Test Stand No. 2 since 1938. RMI's first and primary customer is the U.S. Navy and RMI's first task is to develop a scaled-up version of the original Wyld motor of about 441 newtons thrust to a 31,360 N thrust JATO (Jet-Assisted-Take-Off) unit for heavily loaded seaplanes operating in the Pacific Theater of the war. The JATO is not adopted, though RMI also develops rocket motors for the first U.S. missiles including the Gorgon series and the Lark. But far more significantly, they develop the four-barrel 26,675 N thrust motor for the Bell X-1 that achieves the world's first supersonic flight in 1947. Frank H. Winter and Frederick I. Ordway, III, Pioneering American Rocketry: The Reaction Motors, Inc. (RMI) Story, 1941-1972, AAS History Series, Vol. 44, passim.

Dec. 20 Led by retired Air Corps Capt. Claire Chennault, volunteer American pilots in the Flying Tigers, or American Volunteer Group, enter action in China to help Chinese forces protect the Burma Road. The road is now vital, since the Japanese have occupied China's principal coastal seaports. On July 4, 1942, the group is merged into the Army Air Forces. Roger Bilstein, Flight in America 1900-1983, p. 153.

Dec. 30 The Army Air Force requests that the National Research Development Council begin development of controlled-trajectory bombs. This leads to the Azon guided bomb. E.M. Emme, ed., Aeronautics and Astronautics, 1915-1960, p. 42.

1966

Dec. 3 The Communication Satellite Corp.'s Intelsat 2-A, also known as "Lani Bird," Hawaiian for "Bird of Heaven" and launched on Oct. 27, 1966, begins commercial service. It is placed in orbit above the Pacific Ocean to provide TV and telephone communications between the U.S. and Japan and Australia, and the U.S. mainland and Hawaii. The satellite's apogee motor malfunctions, however, leaving it in a lower orbit than the planned geosynchronous orbit although it is able to provide limited services. Washington Evening Star, Dec. 3, 1966, p. A3.

Dec. 7 ATS-1, the first satellite in the Applications Technology Satellite program, is launched by an Atlas-Agena D booster and later placed in a near-synchronous orbit over the Pacific. The 350-kilogram ATS-1 is one of the most versatile satellites ever developed and carries 15 communications, technology and scientific experiments. These include a camera system for cloud-cover photos and a transponder for voice communications between ground stations and aircraft in flight. It can therefore transmit TV and voice communications among stations in North America, Asia and Australia, as well as weather data. Washington Post, Dec. 21, 1966, p. A15.

Dec. 12 A new Soviet launch site near Archangel, just south of the Arctic Circle, is discovered by British grammar school students in Northamptonshire, U.K., after they tracked several Cosmos satellites and fed the information into a computer. The students, ranging in age from 13 to 17, are from the Kettering Grammar School that is equivalent to a U.S. high school. Their equipment also includes a used war surplus classroom communications receiver and a borrowed tape recorder. Their instructor is Geoffrey Perry, who has been instructing his students to track satellites since 1964 with additional assistance from physics and chemistry teachers. New York Times, Dec. 21, 1966, p. 25; Aviation Week, Dec. 19, 1966, p. 17.

Dec. 14 Biosatellite 1, carrying more than 10 million tiny living organisms, is launched to study the effects of weightlessness and space radiation on the growth of plants and animals. Following 47 orbits, it was expected to fire a retro rocket for the satellite to re-enter Earth's atmosphere over the Pacific and deploy a parachute. Then the satellite was to be recovered aerially by aircraft for return to NASA laboratories for analyses of the result. However, the retro rocket fails to fire and the satellite remains in orbit until Feb. 15, 1967. New York Times, Dec. 19, 1966, p. A3.

Dec. 21 The Soviet Union launches its Luna 13 spacecraft to the moon. On Dec. 24 it ejects a hard-lander capsule on the lunar surface in the Ocean of Storms where it takes panoramic photos and uses a ground penetrometer to measure the strength of the lunar soil and also takes radiation measurements. David Baker, Spaceflight and Rocketry, pp. 203-204.

Dec. 22 The HL-10 Lifting Body achieves its first free flight when it is air-launched from a Boeing B-52 flying at 45,000 feet. Shortly after its release, HL-10 pilot Bruce Peterson maneuvers the Lifting Body to a 320 kph landing. The purpose of the HL-10 and other Lifting Bodies is to help contribute to the design of future manned spacecraft capable of maneuvering in flight and pilot-controlled ground landings. Lifting-body designs are regarded as contributing toward the later design of the Space Shuttle. NASA Flight Research Center News Release.

1991

Dec. 4 Pan American World Airways, once the leading airline in the world and the first to offer Trans-Atlantic, Trans-Pacific and around-the-world passenger service, and the first to introduce the revolutionary Boeing 707 and 747, goes out of business. Following years of decline after the retirement of its founder, Juan Trippe, the airline failed to obtain last-minute financing from Delta Air Lines and was forced to cease operations. David Baker, Flight and Flying: A Chronology, p. 487.

Dec. 7 A European Telecommunications Satellite Organization communications satellite, Eutelsat 2, is placed into orbit from Cape Canaveral, Florida, using an Atlas-2 booster. The satellite is designed to relay television and radio telephone signals throughout Europe. The French-built Eutelsat-2 is the third in the series. Ihor Y. Gawdiak and Charles Shetland, Astronautics and Aeronautics, 1991-1995, p. 155.

KELLY HERING, 25

Spacecraft engineer, Planet

Photo by Beck Diefenbach

The workers at Planet, a 375-person company in San Francisco, like to say they are "democratizing" Earth observation, a field once dominated by intelligence agencies and a few large companies. Formerly called Planet Labs, the company operates 58 spacecraft about the size of a loaf of bread called Doves. Each 4-kilogram Dove orbits at such a low altitude that it falls back into the atmosphere in about two years, which means new Doves must join the flock about every three months. In 2015, Planet acquired five spacecraft with its purchase of RapidEye AG, a German geospatial information company. In September, Planet won a $20 million award from the U.S. National Geospatial Intelligence Agency. As a spacecraft engineer specializing in mechanical design, Kelly Hering is responsible for Dove's optical payload, avionics, communications, power, and attitude determination and control systems.

How did you become a spacecraft engineer?

In high school, one of my mentors suggested I apply to an engineering summer program. I found one that suited my love of design and desire to help others: an Engineering for Community Service program at Columbia University. I came home having designed an irrigated garden for senior citizens to use inside a nursing home. This jump-started my interest in mechanical engineering, as I could use my skills to design physical things to better the world around me. During my sophomore year at Brown University, I joined a student group that was working on a cubesat called EQUiSat. For the next two years, I led the power subsystem team, focusing on the battery pack and solar panel designs. Cubesats, at the time, were an exciting, new prospect for space — they were a more affordable way to design, test and launch a satellite. Until Planet, this was really only utilized by universities like Brown. Planet is pushing the industry forward and challenging the status quo of decade-long, multimillion dollar government satellite programs. So when I had the unique opportunity to continue designing on cubesats at a company on the forefront of the "new space" effort, I jumped at the chance.

Designing for a constellation of cubesats pairs typical aerospace design with product design. The aerospace portion covers harsh structural environment during launch and a wide array of thermal environments in space. My parts go through extensive testing to de-risk this on the ground, and we use telemetry as a feedback mechanism to understand how we perform on orbit. The other challenge is in designing for an entire fleet, or "flock" as we call it at Planet. When the number of satellites produced grows from one to 10 to 100, things like design for manufacture and assembly become increasingly important, much like in product design. The key differences here are that we can never fully test in our true environment, and once we ship the satellites, they can't be recalled.

What kind of things will be going on in space in 2050?

The SpaceX first stage landings and the beginnings of nanosatellite launch systems to name a few. I expect these efforts to help make reaching space in 2050 not only much cheaper but much more accessible. To that end, I hope civilians will be exploring this space frontier by 2050, and our constraints and challenges will morph accordingly. We will be charged with designing space habitats, orbital fuel transfers and more advanced propulsion systems. I hope the aerospace industry will utilize the iterative and innovative techniques developed at commercial space companies like Planet to push the boundaries of what is possible from now through 2050. ★

AIAA Congressional Visits Day

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Congressional Visits Day
Wednesday, 29 March 2017

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

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"I continue to participate every year because it's important to me to keep learning more about these pertinent issues and to dedicate my time to help our community develop and grow."

*—**Kayleigh Gordon,** Aerospace Engineering graduate student, Ohio State University*

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