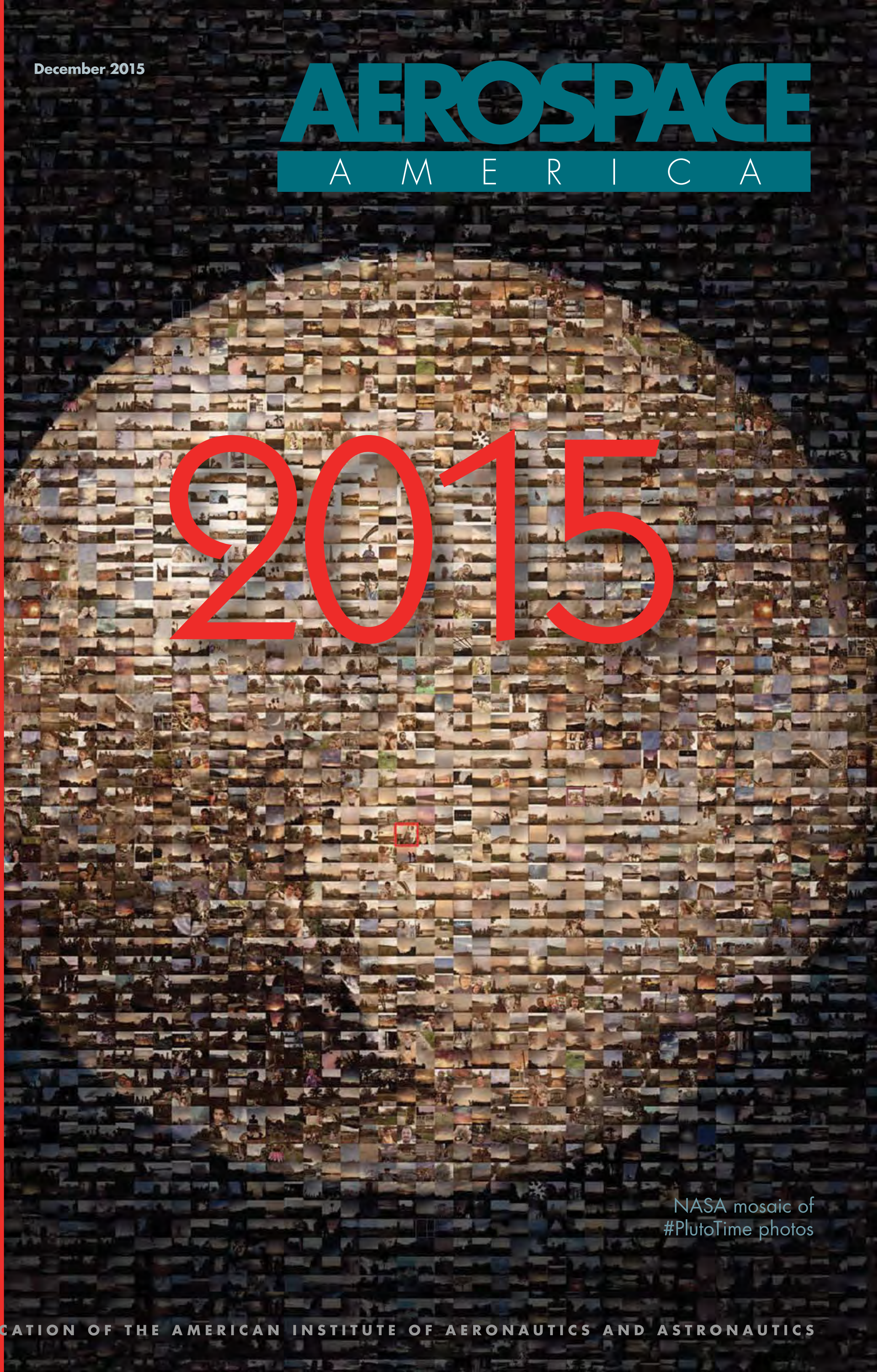
December 2015

AEROSPACE AMERICA

In Review

2015



NASA mosaic of #PlutoTime photos

A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

AEROSPACE AMERICA

December 2015

THE YEAR IN REVIEW

The most important developments as described by AIAA's Technical and Program Committees

BULLETIN

ON THE COVER

The red box in the center of this NASA mosaic marks a photo of Clyde Tombaugh, who discovered Pluto in 1930.







Aerospace America (ISSN 0740-722X) is published monthly by the American Institute of Aeronautics and Astronautics, Inc. at 12700 Sunrise Valley Drive, Reston, Va. 20191-5807 [703/264-7500]. Subscription rate is 50% of dues for AIAA members (and is not deductible therefrom). Non-member subscription price: U.S., $200; foreign, $220. Single copies $20 each. **Postmaster: Send address changes and subscription orders to address above, attention AIAA Customer Service, 703/264-7500.** Periodical postage paid at Herndon, Va., and at additional mailing offices. 40,000 copies of this issue printed. This is Volume 53, No. 11

AEROSPACE AMERICA®

is a publication of the American Institute of Aeronautics and Astronautics

Ben Iannotta
Editor-in-Chief
Kyung M. Song
Associate Editor
Greg Wilson
Production Editor
Jerry Grey
Editor-at-Large
Christine Williams
Editor AIAA Bulletin

Contributing Writers
Robert van der Linden, Frank H. Winter

Jane Fitzgerald
Art Direction and Design

James F. Albaugh, *President*
James "Jim" Maser, *President-Elect*
Sandra H. Magnus, *Publisher*
Craig Byl, *Manufacturing and Distribution*

LETTERS AND CORRESPONDENCE
Ben Iannotta, *beni@aiaa.org*

QUESTIONS AND ADDRESS CHANGES
custserv@aiaa.org

ADVERTISING MATERIALS
Craig Byl, *craigb@aiaa.org*

December 2015, Vol. 53, No. 11

AIAA
Shaping the Future of Aerospace

Editor's Notebook

The meaning of 2015

The best thing about Aerospace America's annual year-in-review edition might be what it signals about the future.

For one thing, the articles from AIAA's technical and program committees are setting the stage for some good old-fashioned drama to come. Orbital ATK and SpaceX worked hard this year to get their rockets ready to fly again, and a host of customers are counting on them to succeed. SpaceX failed twice this year to land a spent Falcon 9 first stage on an ocean barge, but Elon Musk is probably not the kind to give up easily. The Bigelow Expandable Activity Module should soon be inflated at the International Space Station, possibly setting the stage for a new approach to erecting structures in space.

All that aside, avoiding drama is also a worthy goal. Airliners could soon be tracked anywhere in the world, reducing or eliminating the odds of more cases like the disappearance of Flight MH370.

As significant as these and other events would be, it's also worth reading between the lines of the year-in-review edition for broader trends. You'll find evidence that the global aerospace industry is in the midst of profound changes that are starting to confront what has been the industry's biggest challenge: Reducing the high cost of aircraft, satellites, space probes, access to space and satellite-based communications.

Flip through these articles and you will see the developments that will propel the industry into the future: Startups and new players mean more competition and, hopefully, lower costs; more computer modeling and lab work means fewer costly and risky flight tests; additive manufacturing will result in quicker production and lower parts counts; applying software across multiple missions and technical domains is making it harder for agencies to justify spending lots of money on specialized tools.

Let's get specific:

AIAA's Communications Systems Technical Committee tells us how new launch vehicles and high-throughput satellite technologies are disrupting — for the better — that segment of the market.

From the Software Technical Committee, we hear about a host of new products, including a NASA-funded application suite that can be reused for multiple missions and about the Flightradar24 aircraft tracking website that displays the real-time locations of thousands of planes.

The Structural Dynamics Technical Committee describes numerous advances, including computer-aided-design meshing tools and a computerized apparatus developed in Canada that replicates the vibrations of rotorcraft on the ground, so that designers can more easily reduce pilot and passenger fatigue and physiological stress.

From the Multidisciplinary Design Optimization Technical Committee, we learn about efforts to apply computer code across multiple disciplines to manage uncertainty and improve estimates of operating lives, among other applications.

Those are just a few of the notable trends and developments that I see. You, the reader, will no doubt find others as you take a moment this holiday season to take stock of the industry.

Ben Iannotta
Editor-in-Chief

Corrections

The article, "Mars via the moon," (November, page 24) incorrectly described proposed plans for a lunar base. Crew members eventually will set up permanent infrastructure at the poles, near water needed to produce propellants.

✈✈✈

The introduction to the article, "New life for an old hybrid," (October, page 38) used an incorrect word choice. The Lockheed Martin Skunk Works airship is the progeny of the P-791.

✈✈✈

An entry in Out of the Past (October, page 44) incorrectly described the propellant used during a 1965 test flight of NASA's Lunar Landing Research Vehicle. The article should have said that the rocket motors used the liquid propellant hydrogen peroxide and produced jets of steam.

✈✈✈

The photo of the SpaceX Crew Dragon capsule accompanying the article, "Maximizing Safety," (October, page 21) shows the capsule lifting off during an unmanned test in May. The caption incorrectly stated the stage of flight.

All letters addressed to the editor are considered to be submitted for possible publication, unless it is expressly stated otherwise. All letters are subject to editing for length and to author response. Letters should be sent to: Correspondence, Aerospace America, 12700 Sunrise Valley Drive, Suite 200, Reston, VA 20191-5807, or by email to: beni@aiaa.org.

Events Calendar

2–3 January 2016
2nd AIAA CFD Aeroelastic Prediction Workshop
Systems Requirements Engineering
Structural Dynamics of Rocket Engines Tutorial
San Diego, CA

4 January 2016
AIAA Associate Fellows Recognition Ceremony and Dinner
San Diego, CA

4–8 January 2016
AIAA SciTech 2016
(AIAA Science and Technology Forum and Exposition)
San Diego, CA

25–28 January 2016
Reliability and Maintainability Symposium (RAMS)
Tucson, AZ

14–18 February 2016
26th AAS/AIAA Space Flight Mechanics Meeting
Napa, CA

Participation is Power

Shaping the future of aerospace is no simple task.

AIAA forums and expositions are catalysts for inspired idea exchange, progressive problem solving, and industry innovation.

Shaping the future of aerospace takes passion, discussion, innovation, collaboration, and most importantly, it takes YOU!

AIAA Forums and Expositions

AIAA SciTech 2016
4–8 January 2016, San Diego, California

AIAA DEFENSE 2016
8–10 March 2016, Laurel, Maryland

AIAA AVIATION 2016
13–17 June 2016, Washington, D.C.

AIAA Propulsion and Energy 2016
25–27 July 2016, Salt Lake City, Utah

AIAA SPACE 2016
13–16 September 2016, Long Beach, California

"Your return on investment will be high. The multiple opportunities you have to advance your career personally by learning, to advance your career professionally by networking…is worth the price of admission."

—Lt. Gen. Larry D. James, USAF (Ret.),
NASA Jet Propulsion Laboratory

Learn More! aiaa.org/forums

"The forum is a great place for us to make contacts, network with our customers and talk about new, innovative ideas."

—Rob Fuller, Lockheed Martin

"All sorts of things go on in the hallways, in side meetings; and you really need to be here in person to experience that."

—Jeffrey Puschell, Raytheon Company

"Students…when you present a paper and get published, that fact stays on your resume your entire life."

—Kevin Burns, Northrop Grumman Corporation

Thank you to our participating sponsors.

LOCKHEED MARTIN

AIRBUS

BOEING

BASTION TECHNOLOGIES

HondaJet

DARcorporation
Design • Analysis • Research

SMARTUQ™

XFlow

AIAA
Shaping the Future of Aerospace

16-953

Better flight through shape-shifting materials

by Louis R. Centolanza

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

Air Force Research Laboratory

NASA and FlexSys Inc. this year completed flight tests of the company's shape-morphing control surfaces, called FlexFoils, which are designed to reduce noise and fuel burn. The surfaces were tested on NASA's Gulfstream 3 research jet.

The German Aerospace Center conducted wind tunnel tests on a droop-nose, morphing device for the leading edge of a wingtip.

German Aerospace Center

The Air Force Research Laboratory, FlexSys and NASA completed flight tests of the Active Compliant Trailing Edge on a modified NASA Gulfstream 3 business jet to prove the airworthiness of **FlexFoils** for optimizing fuel efficiency and reducing air loads and airframe noise. FlexFoils are compliant airfoil structures that replace conventional surfaces for seamless, variable camber capability. On the G-3, the FlexFoil sections span 5.5 meters, plus 60 centimeters of compliant fairings on both sides to reduce noise.

High-lift leading-edge-slat devices for transport aircraft are a prominent source of airframe environmental noise near airports. NASA Langley Research Center and Texas A&M University collaborated to optimize designs and prototypes representing a 2D simplification of a highly reconfigurable, superelastic shape-memory alloy-based slat structural treatment, known as a **slat-cove filler**. It alters the flow field to reduce noise without detriment to aerodynamic performance. Recent work explored 3D sweep and taper effects and means for minimizing actuator work requirements. Aeroacoustic tests of 2D and 3D prototype systems are planned, and the 2D testing platform is under development.

The German Aerospace Center designed, manufactured and tested a droop-nose morphing device for the leading edge of a regional jetliner wingtip for the European Union project **NOVEMOR**, or Novel Air Vehicle Configurations: From Fluttering Wings to Morphing Flight. The device has a seamless flexible skin with an optimized ply layup driven by electrical linear actuators and topologically-optimized compliant mechanisms fabricated from superelastic nickel titanium alloy. Wind tunnel testing at the University of Bristol in February showed the structure is able to effectively morph under aerodynamic loads.

The Consortium for Research and Innovation in Aerospace in Québec produced an electric-actuator-controlled morphing wingtip for a Bombardier-type aircraft. International partners include Bombardier Aerospace, Thales Canada, the National Research Council Institute for Aerospace Research (NRC-IAR) and the École de technologie supérieure abd École Polytechnique, as well as Alenia, the Centro Italiano Ricerche Aerospaziali and the University of Naples. The Canadian team controlled the morphing wing during wind tunnel tests to validate the numerical aerodynamic results for a higher laminar flow region with experimental results from infrared tests and kulite sensors. NRC-IAR performed infrared tests and balance and wake-rake measurements.

Spacecraft for future missions face a difficult thermal-control challenge. They must reject a high heat load in warm orbital environments and a low heat load in cold transit environments, requiring radiators with high turn-down ratios. This challenge is being addressed with radiators enabled by shape-memory alloys, which exploit temperature changes to passively morph radiator shape and adjust the heat-rejection rate. Texas A&M, Paragon Space Development Corp., and NASA Johnson Space Center are researching integrated stress and thermal model and prototype structures. Fully physically coupled simulation and thermal vacuum chamber testing of prototypes demonstrated feasibility of the concept.

Boeing and the Army Aviation Development Directorate completed their **Multi-Role Rotor-Adaptive Performance project**, which demonstrated helicopter rotor system technologies that improve aircraft performance and reduce vibrations. The team conducted full-scale design studies, fabricated and tested full-scale actuators, and successfully conducted two wind tunnel tests, including an integrated morphing blades model to explore the benefits of in-flight rotor blade twist variation for hover and cruise performance and vibratory loads.

Arizona State University is investigating the mechanochemistry of thermoset polymers dispersed with **carbon nanotubes** and mechanophores nanoparticles to enable multifunctional properties such as self-sensing and self-healing in polymer matrix composites. Cyclobutane-based mechanophores are being synthesized with funding from the U.S. Air Force and the Army.

A quantum mechanics-based molecular dynamics simulation method is under development to accurately capture mechanophore activation under complex external loading. The influence of nanoparticles on material property enhancement, improvement in elastic/inelastic performance, and thermal and electrical effects are under study.

Collaborating for multi-disciplinary design

by Karen 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:

• **MDO tools**: In July, NASA released **OpenMDAO** version 1.0. This computing platform uses the modular analysis and unified derivatives framework, developed at the University of Michigan's MDO Lab, to efficiently compute coupled-system derivatives and accelerate multidisciplinary analysis. The Air Force Research Laboratory's Multidisciplinary Science & Technology Center (AFRL MSTC), MIT and Syracuse University released the Computational Aircraft Prototype Syntheses program. CAPS supports geometry and meshing for conceptual design, MDO, and high-fidelity physics simulation. The Computational Optimal Design of Engineering Systems laboratory at the University of Arizona released the **CODES toolbox** for computational design, including classification-based adaptive sampling and reliability assessment.

MIT released GPkit, an open-source Python programming-language package for geometric programming-based optimization that supports interactive-design space explorations.

• **MDO methodology**: Researchers at the University of Southampton explored scripted parametric geometry definitions, showing that the geometry-as-recipe idea can circumvent curse-of-dimensionality issues. They also investigated integration of flight-test results into an iterative MDO loop, exploiting advances in rapid prototyping.

Delft University of Technology and the University of South Carolina developed a multi-level fidelity approach in which consistency between fidelities is guaranteed through a coupled adjoint approach.

A Multidisciplinary Research Program of the University Research Initiative **(MURI)** team is developing multi-information-source approaches to multidisciplinary decision-making. The MURI team is composed of Arizona State University, Cornell, MIT, Santa Fe Institute, Texas A&M and the University of Michigan.

Researchers at the University of Illinois developed new, generative-design methods for topology optimization of electro-thermal power systems; they extended direct optimal control for integro-differential optimization problems, and improved hydraulic system efficiency via micro-texture design and surrogate modeling.

MDO methods are expanding to cover more of the system life cycle. An AFRL MSTC-lead Boeing/General Electric team is expanding conceptual design to include power and thermal management, high-fidelity engine models and operations analysis in the OPTImization Multidisciplinary Systems OPTIMUS program.

McGill University's Systems Optimization Lab developed methods to integrate component operating-life predictions, or lifing, into MDO of aerospace product-service systems. The lab, in collaboration with McGill's Computational Fluid Dynamics Laboratory, also applied surrogate-assisted derivative-free optimization to design aircraft electro-thermal anti-icing systems.

North Carolina State University and Brigham Young University explored design of systems better equipped to meet the challenges of unforeseen user requirements, operating environments, and technological advancements. This work identifies which components are critical in enabling changes to the system even after deployment in the field.

Iowa State and Penn State are developing visual analytics tools to support value-driven design of complex engineered systems under uncertainty. These tools will facilitate system decomposition and organizational alignment while optimizing subsystems in a mathematically rigorous framework.

The AFRL MSTC-Virginia Tech-Wright State University Collaborative Center on Multidisciplinary Science researched **topology optimization of multifunctional structures** using multiscale analysis; a new quasi-Newton algorithm QNSTOP for stochastic and global optimization; non-intrusive aeroelastic shape sensitivity analysis; exploration of multidisciplinary design spaces using additive manufacturing and rapid prototyping testing; control of transonic flutter; and a computational MDO design environment for advanced supersonic efficient aircraft.

• **MDO design capabilities**: The AFRL MSTC/NASA Langley Sensitivity Analysis for Multidisciplinary Systems project is extending the FUN3D unstructured Navier-Stokes analysis code with adjoint-based computation of derivatives of transient aeroelastic responses. The goal is to capture critical aeroelastic interactions during aircraft configuration optimization. The Multidisciplinary Analysis and Design Center for Advanced Vehicles at Virginia Tech is developing a computational design environment for MDO of wings of advanced subsonic and supersonic aircraft whose designs are expected to include curvilinear spars and ribs enabled by additive manufacturing.

University of Southampton/ Andy Keane

The ducts and fuselage of the Southampton University Custer Channel unmanned aircraft were produced in the U.K. with 3D printing, using multidisciplinary design optimization. The geometry of the SUCCUAV's ducts resulted from optimizing the trade-offs among lift, drag, weight and cost.

University of South Carolina

Kittyhawk, a blended-wing-body aircraft, was designed with multidisciplinary-design-optimization tools by a team led by VX Aerospace and including North Carolina State University, Stanford University and the University of South Carolina.

Modeling uncertainty for better 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.*

To enable aerospace design under uncertainty, researchers continue to develop non-deterministic methods capable of incorporating various sources of uncertainty.

The Aerospace Systems Directorate of the Air Force Research Laboratory this year conducted fundamental research on goal-oriented, **multi-fidelity algorithms** for mitigating model uncertainties while achieving significant reductions in computational cost. They developed an approach based on the adjoint method, which facilitates both design optimization and model selections.

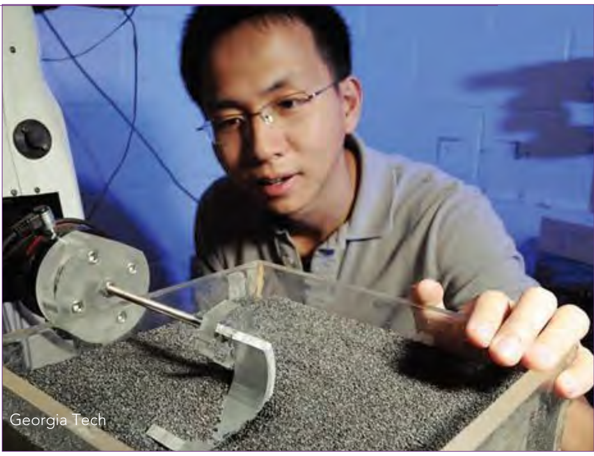
Multi-fidelity design is the process of utilizing all available resources — levels of physics, grid refinement, and discipline coupling — to achieve high-fidelity accuracy at low computational cost. Wright State University is developing a robust and cost-effective multi-fidelity design optimization framework. It incorporates uncertainty quantification techniques, including Bayesian updating and model management. The **Bayesian method** is used to combine additive and multiplicative adjustment factors with a low-fidelity model to serve as a pseudo high-fidelity model. This makes use of all low-fidelity physics, such as a beam model of a wing, with first-order corrections to a high-fidelity model, such as a detailed finite-element model.

The University of Arizona has developed a new approach to design **nonlinear energy sinks** under uncertainty. These devices suffer from high sensitivity to design and loading uncertainties, which can cause abrupt changes in efficiency. However, their nonlinear stiffness properties make them promising for passively reducing structural vibration and acoustic sound pressure.

The Missouri University of Science and Technology, NASA, and Boeing in October started validation and uncertainty quantification of various turbulence models, many of which can be inaccurate in complex flows. This effort also includes robust vehicle aerodynamic shape design under uncertainty.

A notable development from NASA/Boeing/Missouri is uncertainty quantification with stochastic expansions implemented for hypersonic flow and radiative heat transfer models for Titan, Mars, and Earth entry and the design of hypersonic inflatable aerodynamic decelerators for the next generation Mars spacecraft.

Another ongoing research focus for non-deterministic approaches is additive manufacturing, in which variabilities in the process can cause parts to deviate structurally from intended designs. Georgia Tech studied parts fabricated by fused-deposition modeling, and integrated its uncertain characteristics into the developed framework. The framework matches probabilistic behavior of coarse-scale, low-fidelity and fine-scale, high-fidelity models via an optimization procedure, enabling performance prediction and certification of printed parts. Katholieke Universiteit Leuven in Belgium also is studying how material properties are affected by variability in additive manufacturing processes.



Studying terradynamics: To measure how robotic legs interact with granular surfaces, researchers at Georgia Tech move them through poppy seeds.

Epistemic uncertainty represents the degree to which design and analysis tools are validated. To model epistemic uncertainty, Mississippi State University is extending the Bayesian models to integrate a multi-interval representation into a decomposed multilevel optimization framework. Current research focuses on material-product design optimization with both aleatory and epistemic uncertainties. This technology can be applied to design lightweight, multi-functional new materials for aerospace applications.

To tackle high-dimensional uncertain problems, researchers at Stanford University and Delft University of Technology in the Netherlands developed an **efficient and accurate numerical integration scheme**, which benefits many uncertainty quantification strategies. The new scheme, simplex stochastic collocation, bridges the gap between Monte Carlo and quadrature material properties. It proves to be advantageous in high-dimensional uncertain problems, while maintaining the efficiency of quadrature in low dimensions. It also handles non-smooth outputs of interest found in aerospace applications, where small uncertainty in the inputs can lead to abrupt changes in performance.

Simplex stochastic collocation is one of the many novel contributions of Jeroen Witteveen, whose passing in August at the age of 34 was mourned by his colleagues and collaborators worldwide.

Mapping Earth and imaging exoplanets

by Gregory L. Davis

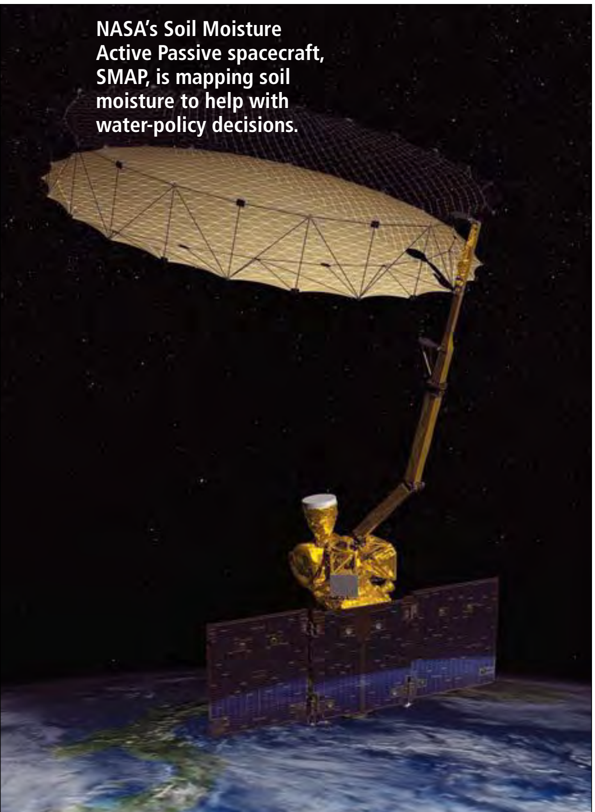
*The **Spacecraft Structures Technical Committee**, formerly the Gossamer Spacecraft Program Committee, focuses on the unique challenges associated with the design, analysis, fabrication and testing of spacecraft structures.*

The **Soil Moisture Active Passive satellite** that NASA launched in January carries a 6-meter-diameter mesh reflector that is the first large, deployable structure to rotate at a high rate relative to a de-spun spacecraft. SMAP continues to provide the first three-day revisit global maps of the Earth's hydrosphere state via its passive radiometer instrument, but its active radar stopped transmitting in July for reasons related to its power supply that are still being investigated.

The SMAP instrument is comprised of a Northrop Grumman Astro Aerospace-built deployable **AstroMesh reflector**/boom assembly and a Goddard Space Flight Center-supplied radiometer. NASA's Jet Propulsion Laboratory supplied the radar, feed, slip-ring, and structural elements. Boeing supplied the spin motor assembly and control electronics.

SMAP's flexible, deployed boom and reflector were designed to achieve exacting surface accuracy and pointing requirements at 14.6 rpm, requiring key analytical and validation methods to be developed during the engineering process. Data from on-orbit operations indicate that the deployed reflector natural frequency is within 2 percent of the prediction, and that objectives for overall antenna performance (surface figure) and rotational stability (mass properties) are achieved at 14.6 rpm.

NASA has initiated several technology developments focusing on **deployable antennas for cubesats**. A reflectarray antenna operating at K-band is baselined for the Integrated Solar Array and Reflectarray Antenna demonstration cubesat, which is scheduled for launch in 2016. An X-band version of this antenna is also baselined for the **Mars Cube One** cubesat, also scheduled for launch in 2016. These reflectarrays are stowed between the spacecraft bus and the launch canister, taking advantage of unused space in that area.

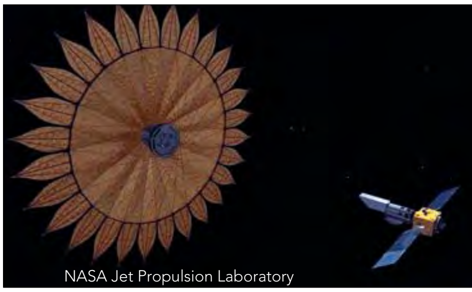


NASA's Soil Moisture Active Passive spacecraft, SMAP, is mapping soil moisture to help with water-policy decisions.

NASA Jet Propulsion Laboratory/CalTech

Preliminary development also began on an **inflatable X-band antenna** that stows in a 1U cubesat envelope. Also, radiofrequency and deployment tests have been completed on a prototype of the 42 decibel Ka-band parabolic deployable antenna; a future version is expected to be used on RainCube, a cubesat mission concept for performing radar science.

In the planetary-imaging domain, technologists from JPL, Princeton University, Northrop Grumman Aerospace Systems, and the Colorado-based companies Roccor and Tendeg made progress this year on a novel technology that would utilize a **free-flying starshade occulter** to make exoplanets visible. Once operational, this flower-shaped occulter will measure up to 40 meters tip-to-tip and will be positioned 30,000 to 50,000 kilometers in front of a space telescope. Its precise petal shape will generate diffraction patterns to mask light from the exoplanet's parent star. The team is implementing very demanding stowed-volume and deployed-dimensional requirements for a full-scale 7-meter-long starshade petal and 10 meter-diameter, half-scale inner disc testbed. It also is utilizing novel, origami-inspired large optical shields to provide the starlight suppression. Concepts based on a radially-deploying **origami "flasher" design** were fabricated this year at several scales, enabling progress toward a baseline design. A 2-meter-diameter, deployable inner disc testbed was fabricated by Roccor and is currently in testing to understand origami kinematics at the 1:10 scale. A flight-like 10 meter-diameter half-scale, micrometeorite-resistant optical shield testbed is also in development and will be completed in late 2017 based on a recent NASA technology award.



NASA Jet Propulsion Laboratory

The Starshade occulter would make exoplanets visible by masking light from the exoplanet's parent star.

Finally, the Spacecraft Structures 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 currently under development by leading experts in the field. Expected publication by AIAA is late 2016.

Reducing risks through structural analysis

by D. Todd Griffith and Anubhav Datta

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

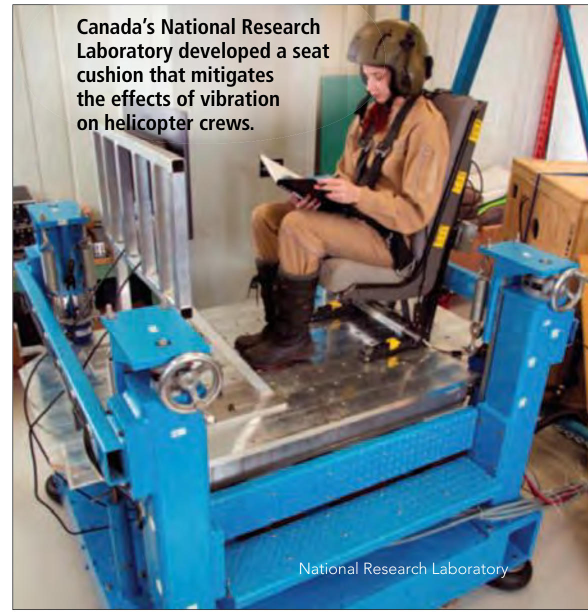
The year saw **many developments in the field of structural dynamics**, from improved rotorcraft modeling to human factors engineering to launch vehicle system identification and new stress analysis for aircraft design.

A team from the University of Maryland and the U.S. Army Aeroflightdynamics Directorate developed CAD-based meshing and multibody modeling tools for a 3D solid-multibody dynamic analysis of a NASA one-quarter scale model of the V-22 Osprey. The novelty of the approach is that it models all root-end parts, constraints and load-paths from first principles to predict the kinematic couplings and dynamic stresses without any one-dimensional beam assumptions. Exact 3D modeling and high-fidelity simulations will enable the design of lighter hubs, morphing blades and increased whirl flutter margins with thinner wings for high-speed tiltrotors of the future. Initial results using the **Army's X3D code** demonstrated the first-principles capability to predict the root-end couplings without relying on model-scale rotor test data to derive equivalent root springs. Current work is focused on coupling the model with the Army's high-fidelity Reynolds-Averaged Navier-Stokes computational fluid dynamics solver.

Artist concept of NASA's Space Launch System. Marshall Space Flight Center developed an operational modal analysis process for the SLS rollout using a finite element model of the vehicle-launcher assembly.

The National Research Council of Canada developed a **human vibration platform** to accurately reproduce vertical aircraft vibration and find ways to reduce the risks to pilots from whole-body vibrations. The profile of an entire flight can be recreated while ensuring safety of the human subjects. The system is capable of reproducing arbitrary time histories with accelerations up to 1 G root mean square and with frequency from 2 Hz to 1,000 Hz, using four electro-dynamic mechanical shakers. A variety of sensors are installed on the platform (1m x 1.8m): accelerometers and pressure pads; electromyography, electroencephalography, electrooculography electrodes (for muscle, brain and eye activity, respectively); goniometers; and heart-rate, skin conductance and respiration monitors. This facility will enable research on the effects of long-term exposure to vibration on human fatigue and physiological stress that adversely impact mission performance.

NASA's Marshall Space Flight Center in Alabama developed an operational modal analysis process for the Space Launch System rollout utilizing a **finite element model** (FEM) of the vehicle-launcher assembly with appropriate crawler boundary conditions. Using rollout mitigates two obstacles encountered in



Canada's National Research Laboratory developed a seat cushion that mitigates the effects of vibration on helicopter crews.

operational modal analysis in flight: the non-stationarity of a variable mass system, and the unknown, or uncontrolled, generally narrow-band, input forcing functions. The rollout input forcing functions, though uncontrolled, are dominated by broadband quasi-random forcing. The process uses acceleration frequency responses at a selected set of sensor locations to construct response shapes across the frequency spectrum. These response shapes are then compared with FEM mode shapes using a standard Modal Assurance Criterion (MAC) to identify response/mode pairs demonstrating high correspondence. The method was validated up to 255 Hz with MAC values above 0.85 with a small lab cart that was instrumented and rolled over rough pavement.

The ability to quickly compute the internal stresses on an airframe for a variety of maneuvers or control sequences opens opportunities for improved design and maintenance of aircraft. ZONA Technology and Boeing, with assistance from the Air Force Research Laboratory, developed a dynamic flight simulation system called the **Stick-to-Stress Dynamic Flight Simulation Program** by combining a flight dynamics model with an aeroelastic solver. The program presents a method of using the stick inputs to compute finite element model load cards for every time step of the simulation. These load cards — when applied to detailed FEMs of the airframe — compute the internal stresses needed for fatigue tracking. Stick-to-stress is an improvement upon traditional simulations because it is capable of computing the incremental loads from airframe dynamics.

Inflatable space habitat ready for deployment

by Harry H. Hilton

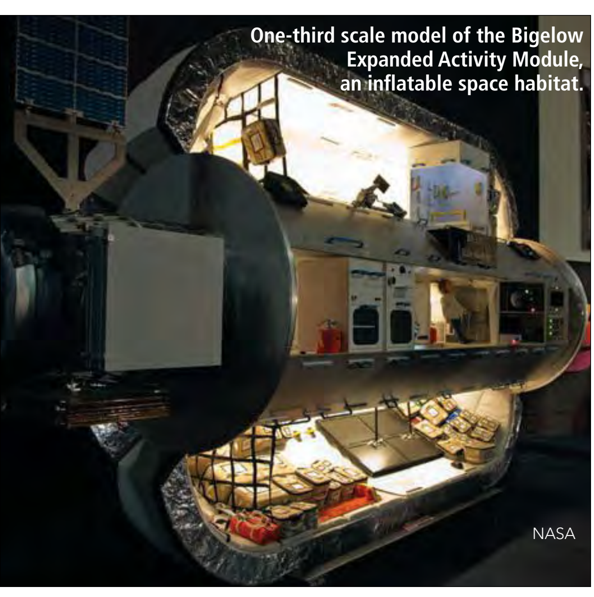
*The **Structures Technical Committee** works on the development and application of theory, experiment and operation in the design of aerospace structures.*

NASA is poised to add an addition to the International Space Station to temporarily expand it from eight rooms to nine. The new room will be like no other on the station, and will be easy to install: It'll connect to a docking port, be filled with compressed air and, voilà, an instant space habitat. This deployment is the result of 15 years of research and development by Bigelow Aerospace of North Las Vegas, Nevada, on the **Bigelow Expandable Activity Module**, or BEAM.

Initially scheduled for a September launch, BEAM's test deployment has been delayed by the June explosion of a SpaceX Falcon 9 rocket on its way to the ISS. Once BEAM reaches its destination, it will undergo two years of intensive testing in what will amount to a trial run for inflatable spacecraft, a technology that could play a significant role in future human spaceflight and low-Earth orbit commercial ventures.

The inflatable spacecraft structures technology was pioneered at NASA's Johnson Space Center in Houston during the 1990s under the **TransHab project**. Bigelow Aerospace licensed the patents and with NASA's help is poised to add this module to the ISS for three years. It is to be the first human-rated inflatable structure ever used in space.

The Adaptive Intelligent Materials & Systems Center at Arizona State University is developing **physics-based multiscale modeling techniques** for composites and nanocomposites, bridging atomistic to structural scale with funding from the Air Force Office of Scientific Research and the Army Research Office. A quantum-mechanics-based molecular dynamics approach is being developed to capture stress-induced covalent bond dissociation. A novel interphase model allows the polymer molecules to entangle and physically interact with the carbon fiber surface, providing an accurate representation of interface properties. The nanoscale information pertaining to covalent bond dissociation is used to define scalable parameters that are further integrated into damage models at higher-length scales with funding from the **Office of Naval Research**.



One-third scale model of the Bigelow Expanded Activity Module, an inflatable space habitat.

NASA

The Air Force Institute of Technology has been researching additive manufacturing of objects made from plastics and metals. Several specimens have been produced and analyzed, such as a projectile considering optimization of the topology and a frame for an icosahedron. The first product was shot into a concrete target and reacted in a very favorable way compared to a projectile produced in the normal fashion. The second project was to analyze the performance under external loading both from a dynamic instability point of view leading to chaotic behavior and from a collapse consideration. Experiments were carried out to determine the correctness of the finite elements procedure.

MIT researchers have developed a composite manufacturing technique that does not require the use of large conventional ovens or autoclaves. This was achieved by integrating an aligned **carbon nanotube film** into the top surface of an aerospace-grade composite structure, and applying current to the carbon nanotube film to process the composite via Joule heating. The team conducted curing experiments with common carbon fiber reinforced composites used in aircraft components and found that the new 'out-of-oven' technique can yield composites of equal or greater quality than conventional oven-based techniques while consuming 99 percent less energy during the curing process. The researchers believe that this new "out-of-oven" approach serves as the new benchmark for energy-efficient techniques for manufacturing aerospace composites.

Manufacturers and engineering firms in the advanced composites sector can now use new software developed at Purdue University to reduce the design cycle of materials and structures, and analyze models too complex for existing methods. **AnalySwift**, a commercial software provider based in Utah, launched SwiftComp, technology that provides efficient, high-fidelity modeling of composites and reduces analysis times without a loss of accuracy, while capturing details of composites that were unreachable using traditional methods. The company licensed the technology, which was developed at Purdue.

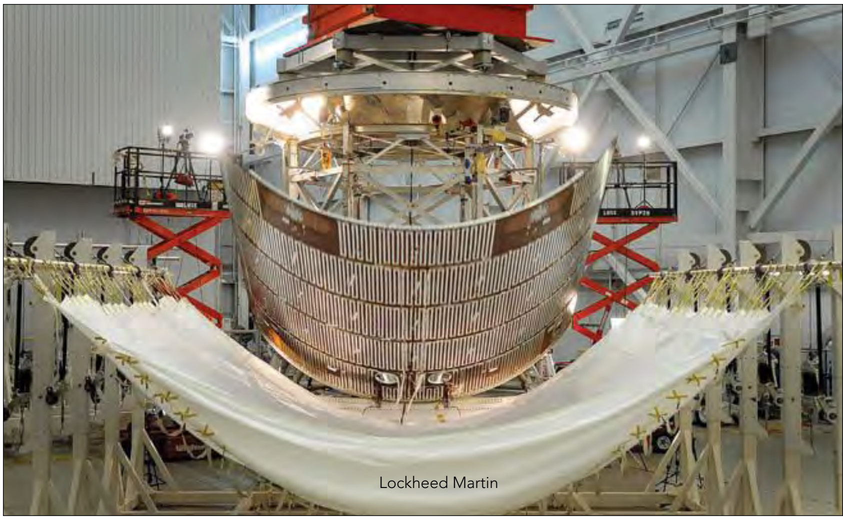
Bigelow Aerospace

Artist's rendering of the Bigelow Expandable Activity Module attached to the International Space Station. The module will be launched to the space station on a SpaceX flight.

Surviving fires and atmospheric entry

by Ameer G. Mikhail, Adam E. Goss, Scott R. Wacker and Gregory J. Czarnecki

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



A protective panel for Orion's service module is jettisoned during testing at Lockheed Martin's Sunnyvale, California, facility. This test series evaluated design changes to the spacecraft's fairing separation system.

The Air Force Research Laboratory in Ohio pursued several notable efforts in 2015 in the field of aircraft and crew survivability:

Researchers undertook a **crew-compartment fire survivability** project in which they investigated the effects on combat personnel from extreme temperatures, oxygen depletion, toxic gas accumulation and visual degradation by smoke. Occupant survivability was assessed in terms of time-to-incapacitation relative to physiological limitations published in medical literature. A statistical model was developed from the test data, from which probability-of-incapacitation could be estimated. Data from this test series indicate that occupant incapacitations can be driven to zero, when fires are extinguished rapidly, when ventilation is increased, and when emergency egress can be executed.

A live fire test and evaluation program was begun for the **KC-46 fuel tanker** against ballistic and advanced threats. The LFT&E program is pursuing innovative data-collection and analysis techniques. These techniques are providing critical input for model development and validation for use in future LFT&E programs. Correlation between test results and model predictions are demonstrating that the vulnerability analysis can be combined with strategic, statistically significant test programs to provide accurate platform vulnerability assessments at substantially reduced cost and schedule when compared to a test-only approach.

Researchers investigated the effects of a high-energy laser on backed aircraft composite materials under controlled conditions. Test specimens were immersed in a high-velocity airstream during quantification of penetration times and back-surface temperatures as a function of laser irradiance. Results are being used to develop laser-damage effects models that will ultimately transition into laser-enabled aircraft vulnerability assessment codes.

NASA and other agencies undertook notable survivability work as well:

For survivability efforts in non-aircraft fields, such as in space systems, NASA, through its prime contractor Lockheed Martin, is performing structural and human survivability tests on its **Orion crew transport capsule**. Test information is also shared with NASA's three space commercialization contract winners for use in their independent capsule designs (SpaceX's Dragon, Boeing's CST-100, Sierra Nevada's Dream Chaser).

NASA continued to study the valuable data from the December 2014 launch and ocean retrieval of the SpaceX unmanned Dragon capsule for human survivability input for g-loading, forces on human body, spacesuits cooling adequacy, radiation levels, and capsule cooling system capacity. Space survivability also had it share of recent tragic events, such as Orbital ATK's **Antares rocket exploding** at Wallops Island in Virginia in October 2014 and SpaceX's Falcon-9 rocket explosion over Florida in June.

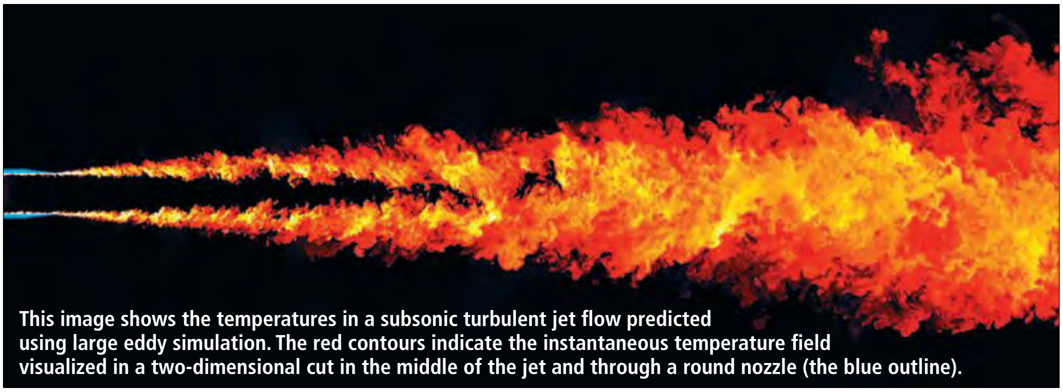
NASA's Jet Propulsion Laboratory has started testing a larger braking system of inflatable drag devices for its 18- to 40-ton Martian human explorer vehicle for its crew survivable landing on Mars. This system dwarfs the braking system used for the 1-ton Curiosity landing rover, which NASA landed on Mars in August 2012.

When it comes to survivability in civil aviation, a pressing issue remains airliner tracking and the cause of the March 2014 disappearance of **Malaysian Flight MH370**. Since then, a short-term solution embraced by the International Civil Aviation Organization is to require pilots to report their location every 15 minutes. The U.S. NTSB has recommended a stricter, longer-term solution that would require location reporting every minute through a new, modern automatic transmitting-tracking system to be developed.

Flying quiet

by Dennis McLaughlin and Anthony Pilon

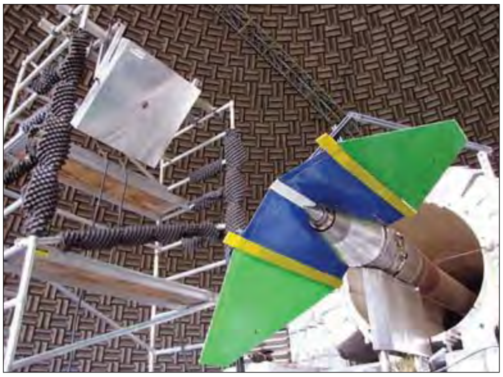
*The **Aeroacoustics Technical Committee** addresses the noise produced by the motion of fluids and bodies in the atmosphere and the responses of humans and structures to this noise.*



This image shows the temperatures in a subsonic turbulent jet flow predicted using large eddy simulation. The red contours indicate the instantaneous temperature field visualized in a two-dimensional cut in the middle of the jet and through a round nozzle (the blue outline).

Cascade Technologies

Noise generated by fluid flow is an important factor in the development of aerospace systems and ground vehicles. Development and operation costs are often directly correlated with **radiated noise**, so the demand for noise reduction will continue to be important for both military and commercial systems. In 2015, the aeroacoustics research and development community made advances to address these demands.



NASA Glenn Research Center

A scale model of an aft deck and tail of future supersonic airliner undergoes acoustic tests for exhaust noise at NASA's Glenn Research Center.

A scale-model of a low-noise conceptual N+2 (two generations from today's aircraft) supersonic airliner was tested in the **Aero-Acoustic Propulsion Laboratory** at NASA's Glenn Research Center in Cleveland. The model incorporated an inverted velocity profile jet flow with modeled airframe surfaces that simulate the aft end of a low-boom vehicle. Far-field and noise source distribution measurements were acquired to validate empirical models and physics-based simulations of exhaust flow-airframe interaction noise sources, shielding and reflection. These recently developed tools will be used in system studies to demonstrate the feasibility of a supersonic airliner that would be quiet enough to meet noise regulations.

Engine nacelle acoustic liners provide significant aircraft fan noise reduction, but further improvements in noise reduction capacity and bandwidth are needed. NASA and Honeywell Aerospace tested a fan model with an advanced multiple-degree of freedom, or MDOF, liner designed at NASA's Langley Research Center in Virginia. Preliminary results show that the MDOF liner provides additional broadband noise reduction relative to a current single-degree of freedom liner. These data will be used to refine the liner models and design codes to optimize future MDOF liners.

Together with academic partners at PPRIME Institute in Poitiers, France, and the California Institute of Technology, researchers at Cascade Technologies in Palo Alto, California, are leveraging high-performance computing and state-of-the-art hybrid modeling to perform **high-fidelity large-eddy simulations** of turbulent jets. Far-field noise predictions for an isothermal, Mach 0.9 jet matched the companion experimental measurements to within 0.5 decibel for relevant frequencies. An extensive LES database collected during the simulation is being mined to inform reduced-order models for wide application.

Researchers at Penn State are continuing to develop of the fluidic insert concept for on-demand noise reduction of tactical aircraft exhaust noise. Experiments are underway with a ¼ scale engine model at GE Aviation with ASE FluiDyne support. An alternate **on-demand noise reduction** concept is being explored at Lockheed Martin. This concept reduces jet noise via reconfiguration of variable geometry nozzle hardware to replicate a forced mixer nozzle.

The increased presence of advanced noise-test facilities in the automotive industry demonstrates how aerospace technology in aeroacoustics is benefiting broader and larger industries. There has been significant progress in developing test facilities for full scale **automotive wind noise testing** since the early 1990s. The test technology is critical to the development of modern vehicles, and numerous aeroacoustic wind tunnels have been recently commissioned for automotive wind noise testing.

Many new climatic wind tunnels also feature acoustic test capabilities for engine and drivetrain component testing. These test capabilities will continue to enable the development of vehicles with better wind noise attributes, fewer problems with sunroof "booming," and lower noise levels for auxiliary systems.

Visualizing air density

by David H. Plemmons and Thomas P. Jenkins

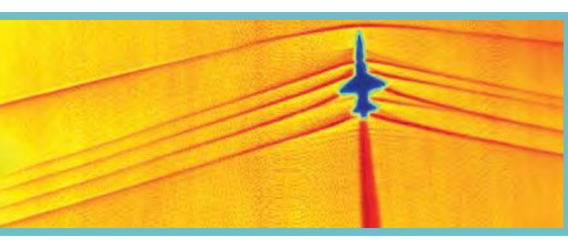
The ***Aerodynamic Measurement Technology Technical Committee*** *advances measurement technology for ground facilities and aircraft in flight.*

Researchers at NASA's Armstrong and Ames research centers this year worked with the U.S. Air Force Test Pilot School to capture images of changes in air density around a T-38 trainer jet using updated forms of schlieren photography, the imaging technique named from the German word for a streak.

Specifically, Armstrong and Spectabit Optics added a subpixel algorithm to the **Ground-to-Air Schlieren Photography System**, or GASPS, a telescope-based system developed in 2011 by MetroLaser of California. Spectabit Optics, a spin-off of MetroLaser, refined the previously developed Polar Analysis Synthetic Schlieren, or PASS, algorithm to include sub-pixel resolution and other filters. The algorithm allowed for computation of the imagery in post-flight analysis so that more details could be extracted from the raw images. The GASPS work in 2015 is a result of many years of improvements since the 1990s, when Leonard Weinstein, then of NASA's Langley Research Center in Virginia, pioneered the film-based, sun-edge method.

Researchers at Ames made advances this year in the **Air-to-Air Background Oriented Schlieren**, or AirBOS, technique. The T-38 was imaged from above using two high-speed Phantom v641digital cameras on a NASA King Air , with the desert vegetation of the Supersonic Flight Corridor near Edwards Air Force Base in California as the background. The results compared favorably to manufactured backgrounds.

This year, Sandia National Lab's wind tunnel team in Albuquerque, New Mexico, acquired **Particle Image Velocimetry, PIV,** movies in a high-speed testing facility. This appears to mark a first among researchers around the world. Sandia worked in partnership with Spectral Energies of Ohio to create high-speed, time-correlated velocity fields. A specialized laser known as a pulse-burst laser was used in 2015 to progress PIV from measuring static images of velocity vectors to acquiring time-correlated velocity fields — that is, movies. Until this year, acquisition of PIV movies was possible only in low-speed flows. The demanding needs of high-speed aerodynamics require this new laser technology to deliver large amounts of energy in bursts of pulses at repetition rates reaching 500 kHz. Data already are providing new physical insights for modeling and simulation.

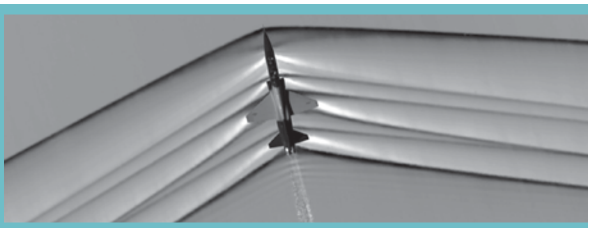


Ground-to-air Schlieren Photography System image of a T-38 taken with the sun as the light source.

NASA Ames Research Center

Researchers from NASA Langley Research Center, the National Institute of Aerospace and Spectral Energies collaborated to perform **femtosecond laser electronic excitation and tagging**, or FLEET, velocity measurements in Langley's 0.3 meter transonic cryogenic tunnel at high Reynolds number conditions. Accuracies and precisions of the single-point measurements were generally on the order of 1 meter per second. The FLEET system was able to measure freestream velocity fluctuations as low as 0.05 percent when the facility was operated at a Mach number of 0.75.

Optical mass flow measurements were performed in a supersonic wind tunnel at Arnold Engineering Development Complex. Tunable diode laser absorption spectroscopy was used to measure velocity, air density and mass flow over a range of supersonic flow speeds up to Mach 5.5. Test section velocities in excess of 800 meters/second were inferred from measured Doppler shifts of supercooled oxygen molecules. Static temperatures were near 50 kelvin. Mass flux uncertainties of 3 percent were achieved.



Schlieren image of an aircraft in flight taken from above, using the desert vegetation beneath as the reference background.

NASA Ames Research Center

Multidimensional measurements have long been sought to answer many open questions in **highly turbulent propulsion flows**. The ability to make 4D measurements (i.e., measurements of flow and flame properties in all three spatial coordinates with adequate temporal resolution) is the ultimate goal, and recent measurements in a supersonic combustor represent a significant step in this direction. Researchers at the Air Force Research Laboratory and Virginia Tech jointly demonstrated a technique, combining endoscopic imaging and tomography, to enable 3D flame measurements in a Mach 2 combustor at a temporal rate of 20 kilohertz. Customized fiber endoscopes were applied to image the target flame from eight different view angles simultaneously at 20 kilohertz. The images captured were then fed into a tomography inversion algorithm, frame-by-frame, to obtain 4D flame properties, including topography, surface area, volume and curvature. These results are used to study both the ignition and stable operation of the combustor.

Testing blended-wing-body concept

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 **Environmentally Responsible Aviation Project** this year completed a series of low-speed wind-tunnel tests of a Boeing blended-wing-body concept vehicle. Among the test goals were to optimize the high-lift system, develop an aerodynamic database and measure inlet distortion due to vehicle-induced flow fields.

Configurations tested included flow-through nacelles with variable-geometry wing edges, both leading and trailing. Testing with ejector powered nacelles and turbine powered simulators installed were also completed as part of the multi-year research.

The Air Force Research Laboratory, Lockheed Martin and NASA reached a milestone in researching the **hybrid-wing-body**, HWB, design, which aims to burn 70 percent less fuel than legacy transports. Results from a 4-percent-scale, semi-span transonic wind-tunnel test in the National Transonic Facility at NASA Langley Research Center — with facility improvements to semi-span test data repeatability — confirmed the aerodynamic efficiency of the HWB and the 5 percent benefit in aerodynamic efficiency of over-wing versus conventional under-wing nacelle installations. This means the HWB design is now suitable for system-level research into technologies for future Air Force airlifters and tankers, as well as advanced commercial freighters.

Boeing's blended-wing-body concept aircraft undergoes high-lift and stability-and-control testing at NASA Langley's 14-by-22-foot Subsonic Tunnel.

Helicopter rotor blades produce strong tip vortices systems that affect the rotorcraft's performance and handling. Further, the rotor blades are highly flexible, making it difficult to accurately predict rotorcraft performance. NASA is considering a new class of hover experiments in wind tunnels under its **Revolutionary Vertical Lift Technology Project**. The goal is to provide hover performance and wake-geometry measurements with greater precision to facilitate validation of modern computational fluid dynamics codes. High-resolution pre-test CFD simulations have been carried out for a rotor operating in the NASA Ames Full-Scale Aerodynamics Complex to assess the effects of walls, floor and ceiling in a wind tunnel on rotor performance and vortex wake.

The AIAA Applied Aerodynamics Technical Committee's Rotorcraft Simulation Working Group held its second hover invited session at the SciTech conference. The goal of this session was to assess different approaches for the hover prediction of S-76 rotor planform for three different tip shapes. Ten institutions across the world participated in the 2015 session. A third series of invited hover sessions is planned for SciTech 2016, focusing on influences such as installation effects, in-ground/out-of-ground etc.

The hybrid-wing-body aircraft at the National Transonic Facility at NASA Langley.

Researchers from Boeing, Bell, Sikorsky, NASA, the National Rotorcraft Technology Center, and Georgia Tech conducted validations of **rotorcraft ice accretion**, deicing and shedding models. The first-principles, multi-physics coupled computational tools advanced the state of the art in icing analysis for rotors. Empirical models are still needed for certain elements for the calibration for roughness effects and the calculation for heat transfer coefficients. The new experimental data sets reduced uncertainty in the empirical models.

In January, progress was made toward identifying a series of increasingly complex aerodynamic benchmark problems at a special forum of SciTech. The problems are suitable for exercising aerodynamic optimization methods in a constrained space. The Defense Department's **High Performance Computing Modernization Program** CREATE Air Vehicles program released three products in 2015: the fixed-wing analysis tool Kestrel 6.0; the rotorcraft analysis tool Helios 6.0; and the conceptual design tool DaVinci 3.0. Kestrel 6.0 introduces full-engine integrated aircraft simulation capability and Helios 6.0 hardens multi-rotor/tail-rotor capabilities. DaVinci 3.0 enables rapid generation of parametric aircraft designs, including the ability to generate outer-mold-lines and basic internal structures.

An exciting year for exploring dwarf planets

by Ryan S. Park

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

After some 2 ½ years of cruise from the asteroid Vesta, NASA's Dawn spacecraft in March entered an orbit around Ceres, the only dwarf planet in the asteroid belt, and became the first spacecraft to orbit a dwarf planet as well as two distinct solar system bodies. With only two functioning reaction wheels, Dawn has been operating nominally with impressive performance and revealed a number of important discoveries of Ceres, including mysterious bright spots. Dawn will continue its primary science sequences through 2016.

Launched in 2006, NASA's New Horizons spacecraft in July made the first encounter with Pluto, the largest known dwarf planet in the solar system, with the closest approach distance of 12,500 kilometers and speed of 14 km/second. With only a few minutes of window for observing Pluto and its satellites, this flawless flyby revealed amazing surface features, including a 3.5-km icy mountain on Pluto. The spacecraft is now en route to its second target, a **Kuiper belt object** called 2014 MU69, and is expected to arrive at the target in 2019.

After four years of orbiting Mercury, NASA's **Messenger** spacecraft used the last of its remaining propellant to end its mission by impacting the surface of Mercury on April 30.

The European Space Agency's (ESA) Philae lander, which was dropped onto Comet 67P/Churyumov-Gerasimenko from the Rosetta spacecraft in November 2014 with the first soft landing on a comet nucleus, beamed an 85-second wake-up message to Earth via Rosetta on June 13. That communication was the first signal from this solar-powered comet lander in seven months since the probe fell silent shortly after its landing.

After a main engine failure in 2010, the Japan Aerospace Exploration Agency, JAXA, planned another attempt in December with its Akatsuki probe to orbit Venus and explore its atmosphere. The resulting orbit will have a similar periapsis compared to the originally planned science orbit, but will be much more eccentric with about four or five times larger apoapsis.

Japan's **Hayabusa-2 mission**, which launched in December 2014, continues on its way to the target asteroid (162173) 1999JU3. The spacecraft is propelled by its ion engine system and will rendezvous with its target in 2018, collect surface sample, and return it to Earth in 2020. Hayabusa-2's secondary payload, called Proximate Object Close flyby with Optical Navigation, was scheduled to perform an Earth flyby in December and will head to a to-be-selected target in the main asteroid belt.

A Russian **Soyuz booster rocket** delivered a resupply cargo ship to the International Space Station in July after a string of failed cargo attempts, including a Soyuz launch in April and a Space-X Falcon 9 launch in June.

During planning for the 2020 Asteroid Redirect Mission, NASA in March selected "Option B," which calls for bringing back a boulder from an asteroid to Earth orbit, rather than the whole asteroid as in "Option A."

The eighth **Global Trajectory Optimisation Competition**, organized by the Jet Propulsion Laboratory, named as winner a team from ESA and JAXA. The competition's objective is to design trajectories for a simplified Very Long Baseline Interferometry mission using three Earth-orbiting spacecraft with electric propulsion and the option to use lunar gravity assists. The winning solution produced 17 different sources observed and 45 total observations in a flight time of three years.

NASA Jet Propulsion Laboratory

NASA's Dawn spacecraft took this image in June. It shows the bright spots of Occator crater on Ceres from an altitude of 4,400 kilometers. The Occator crater is about 90 kilometers across and 4 kilometers deep.

Breakthrough year for icing researchers

by Michael J. Oliver, Andy Broeren, William W. Vaughan 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 Glenn Research Center in Cleveland completed the first ever **large-fan driven rig ice crystal icing test** in its Propulsion Systems Laboratory, NASA's altitude-simulation jet-engine test facility. The laboratory was retrofitted in 2012 with an ice crystal cloud generation system and soon completed a first-ever, small-fan jet engine test, using a Honeywell ALF502-R5. GE Aviation, the industry customer for the more recent test, required the generation of a controllable, conventional ice crystal cloud at various altitude conditions for a large-fan jet engine.

The technical challenge to overcome was that the airflow requirements for the full-scale large-fan jet engine exceeded the air-mass flow rate capabilities of the Propulsion Systems Laboratory, PSL, at Glenn. NASA and customer researchers, engineers and technicians worked together to overcome this challenge by developing a facility interface and driven rig test article specifically targeting the part of the engine that researchers believe is the main region where large- and small-fan jet engines alike are affected by ice crystal icing.

Their achievement is significant in that researchers and engineers from government and industry now have a facility to study test articles operating at high altitude in ice crystal icing environments that apply to both small and large turbofan engines. This covers the full spectrum of commercial aircraft that operate in an ice crystal icing environment. Though PSL was developed specifically for generating high-altitude ice crystal clouds, the successful generation of **conventional icing clouds at above sea level** altitudes (super cooled liquid water) gives researchers another tool to study how inclement weather affects the operation of turbofan engines at controllable altitudes and temperatures well above sea level.

In recent years, NASA has collaborated with the FAA and the French Aerospace Laboratory, ONERA, to investigate **in-flight icing** on large-scale commercial transport airplanes. A major program milestone was achieved this year with the completion of three icing-wind-tunnel test campaigns in the NASA Icing Research Tunnel. A large database of **ice accretion geometry information** was collected for three swept-wing models representing inboard, midspan and outboard sections of the NASA Common Research Model.

A hybrid model design approach was used to reduce the model scale to a reasonable size for the test section. The hybrid model designs utilized a full-scale leading edge section with a truncated afterbody and flap for circulation control. The approach was developed under a NASA research announcement with the participation of the University of Illinois, the University of Virginia, the University of Washington and Boeing.

Aerodynamic data collected during the Icing Research Tunnel test campaigns was used to confirm the performance of the hybrid design method. Flight-scale representative ice accretion was generated on these models and measured with a 3D laser-scanning method developed specifically for this work under a previous research effort. The ice accretion information will be used for development and validation of ice-accretion simulation codes and for aerodynamic investigations to be conducted over the next three years.

A technician at NASA Glenn's Propulsion Systems Laboratory inspects the inlet ducting of the Honeywell ALF 502 engine used for NASA's engine icing validation test.

NASA

Advances in space vehicles

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.*

The X-56A in flight at NASA's Armstrong Flight Research Center in Edwards, California. NASA/Ken Ulbrich

NASA took receipt of the **X-56A Multi-Utility Technology Testbed** from the Air Force Research Laboratory and began flight testing the aircraft in April at Armstrong Flight Research Center in California. The X-56A was designed by Lockheed Martin Skunk Works under contract to AFRL as a test bed for active flutter suppression and gust-load alleviation technology. NASA is testing it under the Advanced Air Transport Technology project. The April flight was the first of eight planned flights for envelope clearance using a relatively stiff wing, to be completed before progressing on to wings having less structural stiffness.

The mobile **Airborne Subscale Transport Research team** from NASA Langley Research Center completed flight tests of the Bat-4 portable unmanned aircraft in April at NASA's Wallops Flight Facility in Virginia. The flights were intended to demonstrate flight beyond visual range, which is a new capability for the team, and included a 6 nautical mile flight at 4,000 feet. Research maneuvers were also completed during the flight for efficient air data instrumentation calibration, real-time global aerodynamic modeling, real-time frequency response estimation and real-time fault detection.

In April, **Blue Origin** performed the first developmental flight test of its New Shepard space vehicle. The test included attaining Mach 3 and an altitude of 307,000 feet. The vehicle is designed to be a reusable and cost-effective means of transporting astronauts and researchers into sub-orbital space.

NASA's Low-Density Supersonic Decelerator

The Low-Density Supersonic Decelerator vehicle, developed and tested primarily by the NASA Jet Propulsion Laboratory, completed a flight test on June 8 at the **Pacific Missile Range Facility** on Kauai, Hawaii. The LDSD is designed to enable payloads up to three tons to be landed on Mars and employs an inflatable structure to decelerate the vehicle. The goal was to test two decelerator technologies: A **Supersonic Inflatable Aerodynamic Decelerator** for robotic missions, SIAD-R, and an improved Supersonic Ring Sail parachute. Lessons were incorporated from a 2014 flight test in which the Supersonic Disk Sail parachute was damaged. The SIAD-R deployed and functioned as planned, just as it did in the 2014 test, but again the parachute failed.

The National Transportation Safety Board held a hearing and issued a press release on July 28, regarding the October 2014 in-flight loss of the **Virgin Galactic VSS Enterprise**, or SpaceShipTwo, vehicle. The investigation found that the accident was caused by the co-pilot prematurely unlocking a movable tail section. It was also stressed that considering human factors, assessing safety, and anticipating human errors are critical to the continued success of manned spaceflight.

In August, the FAA granted Nevada approval to conduct flights at its unmanned aircraft systems test site during the night and up to altitudes of 1,200 feet, expanding its current capabilities. The test site is one of six set up around the country by the FAA for research into unmanned aircraft systems.

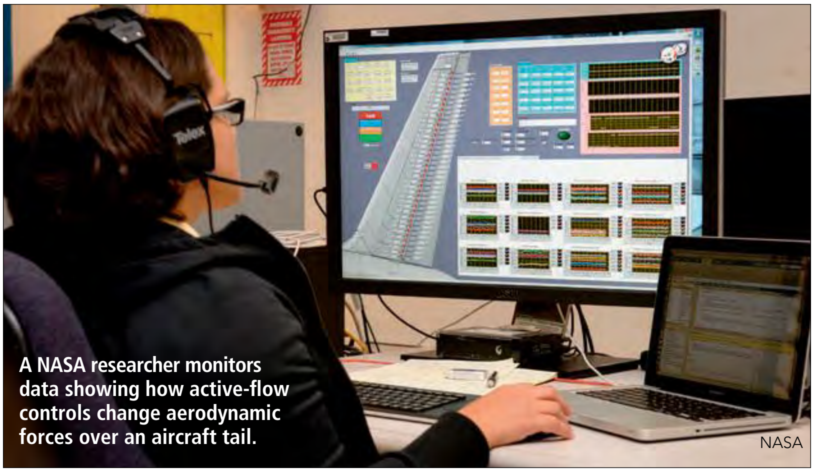
Flow-control technologies move out of labs

by 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.*

The U.S. Air Force Academy and the University of Colorado in Boulder this year experimented on a wing designed to undergo torsional limit cycle oscillation, also known as stall flutter. These flow control experiments and matching simulations suggest that such flutter can be significantly reduced by modifying the flow structure with a jet of air injected through a small slot near the leading edge.

Flow control technologies have transitioned from the laboratory and small scale test vehicles to full-scale aircraft, such as the tail of the Boeing 757 EcoDemonstrator research plane. Boeing concluded tests of this technology on the EcoDemonstrator in April. The application uses sweeping jets, developed at the University of Arizona, to increase rudder effectiveness during large deflections. The goal is to shrink the rudder, which is currently sized to overcome asymmetric thrust when an engine fails. Further research focuses on synthetic jets that need no air supply.



A NASA researcher monitors data showing how active-flow controls change aerodynamic forces over an aircraft tail.

NASA

Engineers need to set manufacturing tolerance when designing aircraft with **laminar flow technologies**. For this purpose, NASA Langley is studying how surface irregularities affect three-dimensional boundary-layer transition. Researchers measured flow instabilities downstream of a backward-facing step inside a swept-wing boundary layer in experiments this year at NASA's Langley Research Center in Virginia. The step has no significant effect on the stationary crossflow instability, but the stationary crossflow interacts with the unsteady disturbances generated by the step, causing a modulation of the unsteady disturbances and an increase in their amplitude. **Particle image velocimetry** measurements were peformed this year to study the flow in more detail.

Syracuse University and the University of Virginia are studying unsteady flow around fish-like fins. Syracuse experimentally studied the wake behind a pitching trapezoidal panel, using traversing stereoscopic particle image velocimetry. The University of Virginia completed the complementary numerical simulations this year. The experimental and numerical results capture similar vortex wake behavior. Ongoing quantitative validation will allow researchers to investigate details of these unsteady flows.

Researchers are tackling challenges faced when using computational fluid dynamics to simulate unsteady aerodynamics in off-design and high-lift conditions. High-order methods have garnered much interest. NASA has engaged to improve models and methods for predicting separated, free-shear, and shock-boundary layer interaction flows. NASA and AIAA identified test cases for these flows. Efforts in high-order methods, turbulence modeling, the use of graphical processing units, and extreme scale supercomputers are also evidenced by the numerous special invited sessions in recent AIAA conferences.

A group of experts completed a multi-year study on how to better teach computational fluid dynamics to undergraduates. Among other things, the study outlines a curricula for undergraduate engineering programs.

The George Washington University and **National Center for Atmospheric Research** developed a model for convection in the sun. Their method simulates compressible flow on an unstructured grid using a massively-parallel high-order method. It is also being used to simulate rapidly rotating oblate stars. Researchers at George Washington are investigating 3D separation around wall-mounted obstacles encountering pulsating flow. Wind-tunnel experiments were performed with programmable vanes downstream producing pulsating inflow. A self-induced vortex propagation mechanism is proposed to explain the observed dynamics.

Researchers at UCLA, the California Institute of Technology and the Illinois Institute of Technology developed models of unsteady aerodynamic loads for **agile and gust-tolerant aircraft**. Their lift response model to periodic actuation proved accurate for both long-time hysteresis and short-time fluctuations. A data-driven vortex model is being explored for nonlinear vortex interaction effects.

Wright State University developed new technology to measure blood flow inside human bodies, for diagnosis and treatment of vascular diseases like stenosis. This technology injects contrast medium into blood and photographs the target with an x-ray imagining system. Unsteady flow field is inferred from successive images using an optimal flow method.

Forecasting disruptive space weather

by Lesley A. Weitz and Luisella Giulicchi

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

Four Magnetospheric Multiscale mission spacecraft developed and tested at NASA's Goddard Space Flight Center in Maryland were launched on an Atlas-Centaur AV-53 in March. The mission will study how the sun's and the Earth's magnetic fields connect and disconnect, which transfers energy between the magnetic fields causing **space weather** that affects terrestrial technologies such as GPS networks and energy grids.

The mission reached an important milestone in July, when the MMS began executing maneuvers to begin formation flying. The spacecraft will fly in a tetrahedral formation to observe electrical and magnetic fields in three dimensions with a goal of understanding and predicting disruptive space weather events. Small and large formation maneuvers are maintained through onboard closed-loop maneuver control using an attitude control system with 12 thrusters on each spacecraft. Attitude sensor data is provided by star and sun sensors.

The **Bell 525 Relentless**, the world's first commercial fly-by-wire helicopter, made its initial flight in Amarillo, Texas, in July. The fly-by-wire technology replaces traditional manual flight controls with a digital interface that provides improved situational awareness and mission control to the pilot. Pilot inputs are transmitted to the flight control computer, which translates those inputs into roll, pitch, and yaw and lateral and vertical guidance and control. Among other things, the test flight demonstrated taxi maneuvers, hover maneuvers and low-speed handling qualities in winds gusts up to 20 knots.

The European Space Agency's **LISA Pathfinder** was set to launch in December to test low-frequency gravitational wave detection. The mission, which will be conducted in collaboration with NASA Jet Propulsion Laboratory, will put two test masses in a near-perfect gravitational free fall, and control and measure their motion with unprecedented accuracy. This will be done with inertial sensors, a laser metrology system, a drag-free control system and an ultra-precise micro-propulsion system.

SpaceX made two attempts to land a spent Falcon 9 first stage on a custom-built ocean platform, which would be a stride toward reusability and the ultimate goal of returning the first stage to dry land. An attempt in January failed after the stabilizing fins exhausted their fuel supply prematurely.

An attempt in April ended when the first stage made a hard landing on the platform and tipped over on the deck. The Falcon 9 first stage is 14 stories tall and reaches speeds of up to 1,300 meters per second. A series of three burns must be executed to stabilize and slow the descent to 2 meters per second. The limited size of the ocean platform requires a landing precision of 10 meters. Previous landing tests in the ocean only showed precisions of 10 kilometers; therefore, four hypersonic fins, each controlled independently, were added to the first stage and are deployed on descent to control the direction of the lift vector.

As the cost of high-performing sensors keeps dropping, complex sensing applications are becoming more available. For example, the Low Cost Surface Awareness, LCSA, system is an affordable approach to providing enhanced situational awareness of an airport's surface operations to tower controllers and air traffic managers. While high-functioning radar systems have been installed at busy airports around the country, they cost $10 million to $25 million, out of price range and unaffordable for many smaller airports. The LCSA system uses aboveground magnetic or infrared sensors to determine when a block, a subdivided operationally-relevant segment of a runway or taxiway, is occupied. The status of the various blocks is displayed to air traffic controllers to supplement visual information and provide safety alerts when another aircraft is detected to be entering an occupied space. This system was tested during August at Teterboro Airport in New Jersey.

The European Space Agency's LISA Pathfinder was readied for launch in Germany in September before departing for the launch site in French Guiana.

European Space Agency

Inching toward ‘push-button’ meshing

By James Masters

*The **Meshing, Visualization and Computational Environments (MVCE) Technical Committee** explores the application of computer science to pre-processing, post-processing and infrastructure in support of computational simulation in the aerospace community.*

An indispensable component to aerospace testing and development is computational modeling and analysis. This often takes the form of computational fluid dynamics, or CFD, which is reinforced by continual advances made in meshing, visualization and computational environments, MVCE.

While **“push-button” meshing** remains an elusive goal, advances in 2015 have brought the technology to the point where meshes can be constructed with relative ease when appropriate surfaces are available.

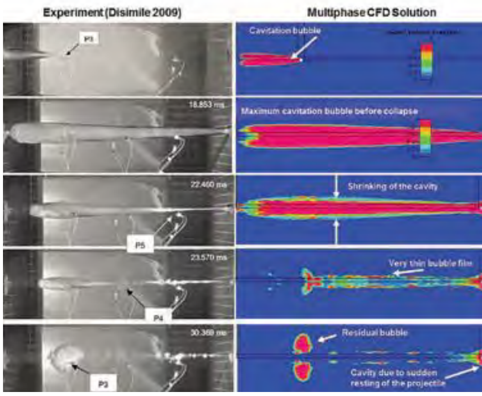
This has effectively moved the bottleneck upstream to the clean-up and defeaturing stage, in which the outer mold lines of an aerodynamic body are smoothed. Mechanical computer aided design, MCAD, and meshing software providers are working together to address this bottleneck by considering CFD earlier in the design process.

This year also saw a continuing trend of exploring **CAD-free meshing** when the original MCAD surfaces are not available. Also gaining popularity is the use of high-order methods, which is necessitating the development of tools for elevating the polynomial degree of linear meshes. This effort is exemplified by meshCurve, an automated low-order to high-order mesh generator being developed at the **University of Kansas**.

The management of large datasets from high performance computing resources, which often are geographically removed from the analyst, presents many challenges. The visualization community is addressing this issue in several ways, including intelligent file compression and 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. Because of the increased use of data-processing techniques that are integrated into the analysis during run-time, the use of “knowledge extraction” is becoming seen by many as more apt than “post-processing.”

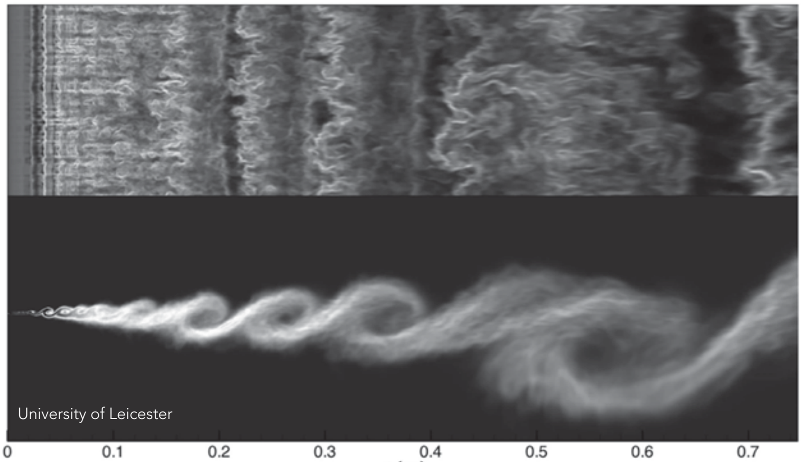
NASA’s 2014 CFD Vision 2030 Study gained momentum in the analysis community this year with several NASA officials citing it at AIAA’s Aviation 2015 Forum. Members of the MVCE community are addressing a key concern expressed in the study, specifically that “mesh generation and adaptivity continue to be significant bottlenecks in the CFD workflow.”

In January, AIAA’s Meshing, Visualization and Computational Environments Technical Committee established a 2030 technical subcommittee. The subcommittee is planning several activities in the upcoming years leading to a Geometry and Meshing Workshop coinciding with AIAA’s AVIATION 2017 Forum. This workshop will examine the current state of technologies and make progress toward the goals outlined in the 2030 study. To ensure relevance to the greater aerospace community, the subcommittee is partnering with others, starting with organizers of the **High Lift Prediction Workshop**. The MVCE community has also embraced the “grand challenges” laid out in the study and taken the step of identifying community members that are focused on one of the three core areas (meshing, visualization or computation environments) and forming subcommittees to come up with strategies for how to address obstacles on the road to 2030. Panels on geometry, meshing and visualization for CFD 2030 were held at SciTech and AVIATION in 2015 with a panel on computational environments to be held in 2016.



CFD Research Corp.

Simulation of a ballistic projectile traveling through a dry bay and into a fuel tank. Modeling real-life events, such as fire initiation inside an aircraft, is critical for improving survivability.



Large eddy simulation of a turbulent mixing layer. The numerical schlieren visualization is shown in plan view (top) and in side view (bottom).

Understanding plasma-assisted combustion, propulsion

by Michael D. White and Timothy J. Madden

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

This year brought continued improvements in terms of physical understanding and novel innovations in the areas of plasma-assisted combustion, propulsion, flow control actuators, aerospace application of lasers and aero optics.

Researchers at **Ohio State University** gained new insight into the kinetic mechanism of energy thermalization in nanosecond pulse discharges by using a combination of kinetic modeling and time-resolved, Coherent Anti-Stokes Raman Spectroscopy, or CARS. Researchers were able to measure the temperature in a diffuse filament for energy transfer spanning several orders of magnitude.

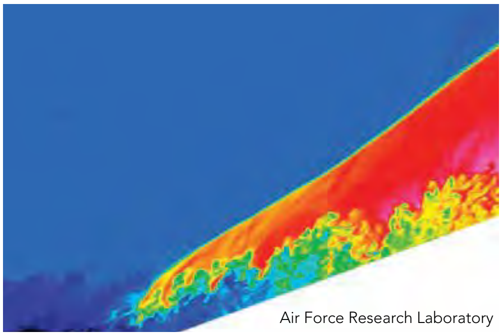
The Applied Physics Research Group at the University of Florida introduced a **milliwatt-class needle actuator** suitable for plasma channels, vortex generation and surface cooling. Electrode configurations tested for a channel configuration showed a three- to 14-fold increase in energy conversion efficiency as compared to conventional actuators, while demonstrating improved heat transfer and cooling.

In **plasma combustion**, a collaboration between CU Aerospace of Illinois, and the University of Illinois, Urbana-Champaign (UIUC) directly compared experimental measurements of plasma-assisted combustion of methane in microwave reactors with simulations. The goal of this work is to create robust simulation tools for modeling the effect of non-equilibrium plasmas on flame composition and stability. In a separate effort, UIUC researchers have developed a new Direct Simulation Monte Carlo solver with automatic unstructured mesh refinement to enable fast resolution of charge-exchange ions (CEX) trace species fluxes in concentrations covering 5 orders of magnitude. Accurate prediction of CEX from ion thrusters is crucial for understanding potential contamination of spacecraft solar cell arrays.

The Missouri University of Science and Technology is developing a **plasmonic nanopropulsion system** for nano/picosats that harnesses the interaction of sunlight with deep-subwavelength nanostructures to accelerate nanoparticle propellant. Sunlight excites surface plasmon polaritons, which accelerates nanoparticles to directly produce thrust with no spacecraft power required.

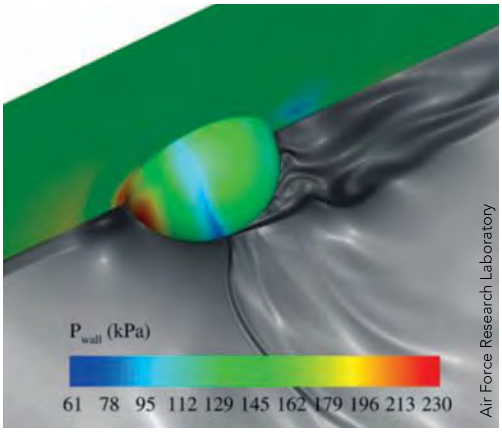
Laser activity this year demonstrates the applicability of the technology in aerospace applications. Researchers at the Ohio State University reported theoretical work exploring the possibility of developing a **carbon monoxide**, CO, laser-based on a gas phase reaction between atomic carbon and oxygen. The work indicated that generation of large amounts of vibrationally excited CO is possible with this approach, and predicted the potential for good laser gain and high power. The work suggested the possibility of using surface ablation of carbon on a high-altitude hypersonic as a means to generate the atomic carbon, and react the atoms with the oxygen in dry air from the surroundings to fuel such a laser. Elsewhere, Colorado State University in collaboration with **Chevron** investigated the ignition properties of methane-air mixtures using a pulsed laser. The work examined compression ratios for the methane-air mixture in the range of 10:1 to 14:1, using a 12 nanoseconds pulsed Nd:YAG at 1064 nanometers for the ignition source and varying fuel-oxidizer ratios. The work highlights the potential for increasing gas turbine and jet engine efficiency using a tunable ignition source.

Aero-optics experimental work revisited problems associated with propagation in a supersonic flow environment. Researchers at the University of Notre Dame, teamed with Innovative Technology Applications of Missouri and the U.S. Air Force Academy, performed **aero-optic distortion measurements** on supersonic boundary layers. They concluded that root mean square optical path difference models correlated with free stream Mach number, even though originally qualified only for subsonic and transonic flows, accurately represented the data through Mach 5. Computational simulation work performed by researchers at the Ohio Aerospace Institute and the Air Force Research Laboratory examined unsteadiness in conjunction with supersonic shock-boundary layer interaction. The work illustrates the computational challenges to capturing the unsteadiness associated with the shock interaction with the separation event, relevant to the **supersonic flows around laser beam** director turrets, as the shock movement will tend to degrade the coherence of beam.



Air Force Research Laboratory

Instantaneous density contours in the compression ramp region from a large eddy simulation of Mach 3 turbulent flow over a 20-degree compression ramp and a cylindrical step.



Air Force Research Laboratory

Instantaneous pressure contours and a density isosurface from a hybrid large eddy simulation — Reynolds Averaged Navier-Stokes simulation of an Auburn University wind tunnel experiment for transonic flow over hemispherical turret.

Preparing thermophysics for new missions

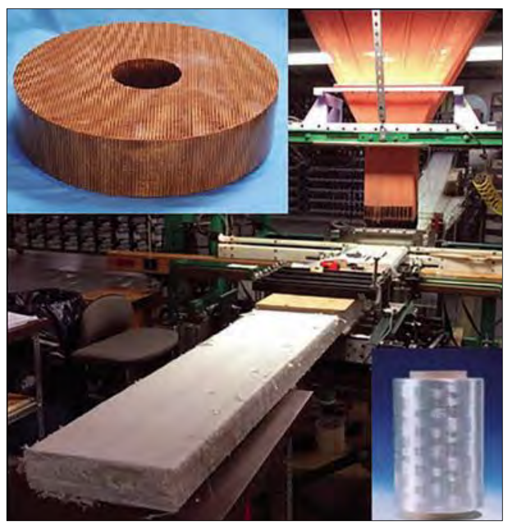
by Aaron Brandis, Alexandre Martin, Tom Schwartzentruber, Michael James Martin, Jay Feldman and Dinesh Prabhu

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

In 2015, the thermophysics community developed fundamental tools at the molecular level, began preparing new technologies for future missions, and saw careful design enable scientific discovery at Pluto.

With support from the Air Force Office of Scientific Research, researchers at the University of Minnesota have developed novel, first-principles methods for studying the coupling of **chemical reactions and energy transfer collisions** to the fluid dynamics of hypersonic shock layers. New potential energy surfaces, PESs, have been constructed and used to compute rate constants for molecular dissociation, as well as nonreactive vibrational and rotational energy transfer. The new PESs were also used in the direct simulation Monte Carlo method, in which the dynamics of each collision is computed on the fly. These new techniques, coupling motion at the atomic scale to macroscopic flow and energy transfer, are being used to develop more accurate models for computational fluid dynamics simulations of hypersonic vehicles.

Future vehicle designs will be enabled not only through better flow simulations, but through new materials. NASA's **woven thermal protection system** is a new approach to produce heat-shield materials. Using precisely engineered 3D weaving techniques, NASA can customize material characteristics to meet the stringent mission requirements for protecting vehicles from the intense heat of atmospheric entry. **3D-MAT**, a fully dense quartz composite material, is engineered for the Orion capsule and is scheduled to fly on the Exploration Mission-1 in 2018.


NASA Ames Research Center

3D-MAT, a woven composite material that will be used for the heat shield of Orion, is produced from quartz yarn. Right inset: After resin infusion and machining, the 3D-MAT material (left inset) is ready.

The challenges of engineering a **spacecraft traveling at hypersonic speeds** are so extreme that the first flight of Orion, the unmanned Exploration Flight Test-1 mission in December 2014, tested the re-entry capabilities of the vehicle. EFT-1 used an extensive suite of instruments, including thermocouples, pressure transducers and radiometers, to measure the thermal response of the front heat shield and the backshell. This extensive data set will be used to validate the models used during flight and will allow engineers to understand how to use simulations and ground tests to predict flight-relevant phenomena. The European Space Agency in February launched its own flight test, the Intermediate Experimental Vehicle, on a Vega rocket. The unmanned IXV reached an altitude of 412 kilometers and re-entered the atmosphere to simulate a spaceplane returning from orbit, splashing down in the Pacific Ocean. The flight marked an important step toward efficient space access and provided researchers with flight data on the behavior of high temperature reusable thermal protection systems.

The success of the **New Horizons** flyby of Pluto and its moons in July depended on advanced thermal management over the wide range of conditions encountered by the spacecraft. This was achieved through careful integration of the spacecraft's power system, waste heat management, electronics power usage and internal heaters. The thermal management system used louvers to prevent overheating at the start of the journey. As the spacecraft approached Pluto, the challenge became keeping the spacecraft warm enough. By channeling waste heat from the spacecraft's radioisotope thermoelectric generator through the fuel tank into the main spacecraft structure, a temperature of 20 degrees Celsius was maintained inside the vehicle. This integrated approach allowed the spacecraft to operate its instruments at their design temperatures at a distance 33 times farther from the sun than Earth's orbit, with a total power budget of approximately 200 watts.

Lessons learned from the **thermophysics of spacecraft entries** have found application to a new problem: assessment of risk from atmospheric entry of asteroids. The first international workshop at NASA Ames in this area brought together experts in the areas of exoatmospheric characterization, atmospheric entry and surface damage simulations, with a view to a physics-based risk assessment framework. The simulations of large, irregularly shaped objects at entry speeds in the range of 12 to 30 kilometers per second have opened opportunities to expand the understanding of thermophysics for dense plasmas and their interactions with asteroidal materials. These analyses will aid the development of appropriate responses to these rare, but potentially catastrophic, events.

Balloons, parachutes and ballutes

by Ben Tutt

The ***Aerodynamic Decelerator Systems Technical Committee*** *focuses on development and application of aerodynamic decelerator systems and lifting parachutes, pararotators, and inflatables for deceleration, sustentation and landing of manned and unmanned vehicles.*

The U.S. Army **Natick Soldier Research Development and Engineering Center** has focused on Precision Airdrop Enhancements for autonomously guided cargo airdrops. One enhancement is bleed-air actuators that control airflow through vents in the top skin of a guided Joint Precision Aerial Delivery Systems parafoil. These small actuators use roughly 1/100th of the force required by conventional trailing edge deflection, provide an improved system response, enable an additional degree of freedom through longitudinal control, have demonstrated increased accuracy, and weigh significantly less than standard actuators and batteries. It is envisioned that bleed-air actuators could be inserted into existing parafoil-based systems, eliminating the need for warfighters to recover airborne guidance units now in use.

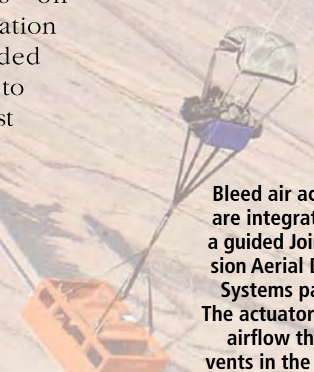
A NASA engineer inspects a ringsail model parachute at the Langley Transonic Dynamics Tunnel.

NASA

Airborne Systems and Near Space Corp., as part of the Flight Opportunities program in the **NASA Space Technology Mission Directorate**, completed two high-altitude flight tests in August of an autonomously guided parafoil parachute recovery system. In each test, a payload weighing 100 kilograms was released from a balloon at an altitude of 18,600 meters. In the first test, the autonomous onboard navigation system guided the payload to a location just 70 meters from its predetermined landing coordinates. In the second test, the payload landed just 33 meters away from its target coordinates. These flights demonstrated a more challenging dynamic deployment of the parachute system than a predecessor test. Each payload fell for 10 seconds under a drogue to build up speed before the semi-elliptical parafoil parachute system was deployed. Customized GPS-based navigation showed the ability to autonomously acquire and maintain desired headings at higher altitudes than previously demonstrated. These tests are a major milestone in showcasing parafoil parachute systems that can be employed above conventional military cargo airdrop altitudes, enabling significant increases in the cross range capability of the recovery system.

A **wind tunnel test of subscale parachutes** was conducted at the NASA Langley Research Center's Transonic Dynamics Tunnel in Virginia. This test supported the ringsail parachute development being undertaken by NASA's Low-Density Supersonic Decelerator project. The test's main objective was to generate a database suitable for modeling the aerodynamic characteristics of ringsail parachutes during flight at Mars. A Disk-Gap-Band parachute was also tested in order to provide data for a direct comparison of aerodynamic performance between ringsail and the parachutes.

Also as part of the **Low-Density Supersonic Decelerator project**, the Jet Propulsion Laboratory conducted a second supersonic flight test with the next generation of aerodynamic decelerators for future Mars missions. A 4.7 meter diameter blunt-body aeroshell was lifted to an altitude above 30 kilometers by a balloon with a volume of 1.12 million cubic meters. The test vehicle was released from the balloon and accelerated to above Mach 4 and an altitude of 54 kilometers where a 6 meter diameter Supersonic Inflatable Aerodynamic Decelerator was deployed to slow the vehicle. The flight also saw the deployment and inflation of a large, 4.4-meter-diameter trailing ballute. A supersonic parachute was also deployed but was severely damaged during supersonic inflation.



Bleed air actuators are integrated into a guided Joint Precision Aerial Delivery Systems parafoil. The actuators control airflow through vents in the top skin of the parachute aiding control and accuracy.

U.S. Army RDECOM

The **Beagle 2 Team** was awarded a 2015 Sir Arthur Clarke Award. Eleven years after its landing attempt on December 25, 2003, Beagle 2 was found on the Martian surface in January 2015 by NASA's Mars Reconnaissance Orbiter. Data showed that Beagle 2 had landed but a number of the solar panels had failed to open completely, preventing the lander from communicating back to Earth.

Final design for 777-9, first flight for KC-46

by Hernando Jimenez, Michael Drake and Willem Anemaat

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

Boeing completed firm configuration for the **777-9**, the first member of the 777X family, which is set to begin production in 2017. Boeing also used its **ecoDemonstrator 757,** the third technology demonstrator of its ecoDemonstrator Program, to continue research into technologies that improve environmental performance. Fifteen technologies were flown more than 194 flight hours. Key technology demonstrations included natural laminar flow wing, energy-harvesting windows, recycled carbon fiber 3D-printed flight-deck aisle stand, end-of-service recycling and the use of active flow control on a vertical tail. Major collaborators were NASA, TUI Airline Group, Stifel Aircraft Leasing and the Aircraft Fleet Recycling Association.

Boeing's 757 ecoDemonstrator was used in 2015 to test technologies for reducing environmental impacts.

Boeing

Machining of the first parts of Airbus' **A330neo jetliner** started in September, and first deliveries are scheduled to start in 2017. Airbus' A350-900 received type certification from the European Aviation Safety Agency and the FAA and delivered the first unit shortly after in December 2014 to launch customer Qatar Airways, which began first-ever revenue flights of this type in January. Airbus also has made progress for the A350-1000 variant for which wing assembly began in August. Bombardier completed the first test flight of its 135-seat CS300 in February, which lasted five hours and reached 41,000 feet. A second flight followed in March.

In March, Gulfstream was awarded the annual National Aeronautic Association **Robert J. Collier Trophy** for development of the G650 business jet.

Cessna Aircraft Co.'s **Citation Latitude** business jet received FAA type certification in June following the aircraft's first Atlantic crossing in May. Deliveries were scheduled to begin in 2015 with NetJets among the first customers.

Dassault's Falcon 8X conducted its first flight in February, marking the start of the flight test certification efforts. The Falcon 8X is a derivative of the Falcon 7X and features several technology upgrades.

Agusta Westland began certification flight testing of its **AW609**, the first-ever commercial tiltrotor, in the powered-lift category. Certification and first delivery are anticipated for 2017 and 2018 respectively. Airbus Helicopters completed the first flight of the H160, its twin-engine medium utility helicopter and first all-new design.

After numerous delays, the first operational squadron of 10 **F-35 Joint Strike Fighters** was announced in August. Boeing completed the first flight of its KC-46 tanker test program with a 767-2C last December, followed by the first flight of a fully outfitted KC-46, the Air Force's next-generation widebody multi-role tanker, in September.

A suite of aerodynamic modifications for the **Eurofighter Typhoon** were demonstrated over a series of flight tests from which engineers claimed improved subsonic agility. The first ever fully autonomous aerial refueling operation was completed in April with the Navy's X-47B carrier based unmanned combat aircraft demonstrator built by Northrop Grumman.

Significant progress has taken place in the development of long-endurance **VTOL UAV** aircraft. Aerovel completed flight trials with two sea-launched prototypes of the 45-lb. tail-sitting Flexrotor to finalize its production configuration. Dzyne Technologies conducted hover flights with its Pathfinder model and is preparing for transition flight tests. NASA's Greased Lightning (GL-10), a battery-powered 10-engine tilt-wing VTOL UAV out of Langley Research Center, has now expanded the flight envelope through the transition corridor into wing born flight. Several follow-on tests are planned for 2016.

NASA Langley/David C. Bowman

NASA's Greased Lightning GL-10, a battery-powered unmanned aircraft prototype, approaches for a vertical landing.

Unmanned aircraft join rise in air traffic

by Karen Marais

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

U.S. air operations continued their gradual rebound this year from the 2009 economic collapse, with 775,673 domestic passenger enplanements in the 12 months ending June 2015, up 3.3 percent from the prior period, according to data published by the U.S. Department of Transportation. In the European Union, passenger arrivals and departures also increased, from 842,219,926 in 2013 to 878,291,692 in 2014, as airlines continued to chase an elusive recovery.

Jet fuel prices continued to drop around the world. In September 2015, the year-on-year price decreased by an average of 46.6 percent, according to the Internation Air Transport Association. IATA estimates that airlines will save a total of $85.2 billion compared to 2014. Combined with higher load factors and higher overall traffic levels, most carriers continued showing good financial results and were rewarded by the stock markets.

Wichita State University and Embry-Riddle University released their annual **Airline Quality Rating** in April 2015. They found that the overall industry performance declined in 2014 to its lowest level in four years. Only three airlines improved performance: **Hawaiian, Alaska and Virgin America**. Overall, performance decreased in the four areas tracked by the study: More flights were delayed, more baggage was mishandled, more passengers were bumped involuntarily and there were more customer complaints.

Safety

Several large aircraft accidents occurred in 2015. In February, **Trans Asia Airlines Flight GE235** hit a highway viaduct and the Keelung River near New Taipei City shortly after takeoff. Forty three of the 58 passengers and crew members were killed. In March, an Airbus A320 operated by Germanwings crashed in a mountainous region in southern France, killing all 144 passengers and six crew members. The preliminary report issued by the French accident investigation board indicates that the pilot intentionally crashed the plane. In July, a flaperon was found on a beach on the French island of Reunion in the Indian Ocean, and in September, French authorities confirmed that it came from MH370.

Airbus

Hawaiian Airlines was one of only three U.S. carriers whose performance improved in 2015, according to the annual Airline Quality Rating by Wichita State and Embry-Riddle universities.

Air Traffic Control

Much of the ATC news centered on the proposed **privatization of control services** and the exploding numbers of drones in the national air space. American Airlines and United Airlines have proposed moving the responsibility for ATC from the federal government to a private, nonprofit entity. Most suggestions propose an organization modeled after **Nav Canada**, an Ottawa company that for 19 years has operated the country's civil air navigation system for the government's Transport Canada agency.

Regarding drones, the year saw almost daily reports of air crews either sighting or having to disrupt operations because of unmanned aircraft near their flight paths.

Research

Flight operations is one of the most popular research topics, especially in the area of trajectory-based operations and the integration of remotely-piloted aircraft. NASA's Aviation Operations and Safety Program is focusing on both of these topics. NASA Ames Research Center hosted an inaugural convention on UAS Traffic Management (UTM) with more than 1,000 attendees from government, industry and academia. For the first time, Google and Amazon publicly presented concepts and plans for future operations.

The FAA is planning a NextGen demonstration of **4D trajectory components** enabled by the Aeronautical Telecommunication Network Baseline 2 standard sometime in early fiscal 2017. The components to be shown are Dynamic Required Navigation Performance, Advanced Interval Management and ATC Winds.

Military operations

Fighting in Syria and Iraq propelled the F-22, a fifth-generation fighter aircraft, into regular combat missions. The extensive delays of the most advanced fighter ever built, the F-35, helped spark a discussion among air power experts over the plane's suitability to fill the close-air-support role played by the **A-10 Warthog**. Reliance of fighter aircraft on in-air refueling has heightened expectation of a new tanker platform, the KC-46, which moved into the flight testing phase. Military use of unmanned planes continued to grow as these platforms have become even more cost efficient, especially while flying intelligence, surveillance and reconnaissance roles where their capability is set to surpass that of their manned counterparts.

Seeking New Members

The Air Transportation Operations Committee is being reinvented and is actively seeking members. Please contact Karen Marais: **kmarais@purdue.edu**.

Trove of data from Antarctic balloon missions

by Paul Voss

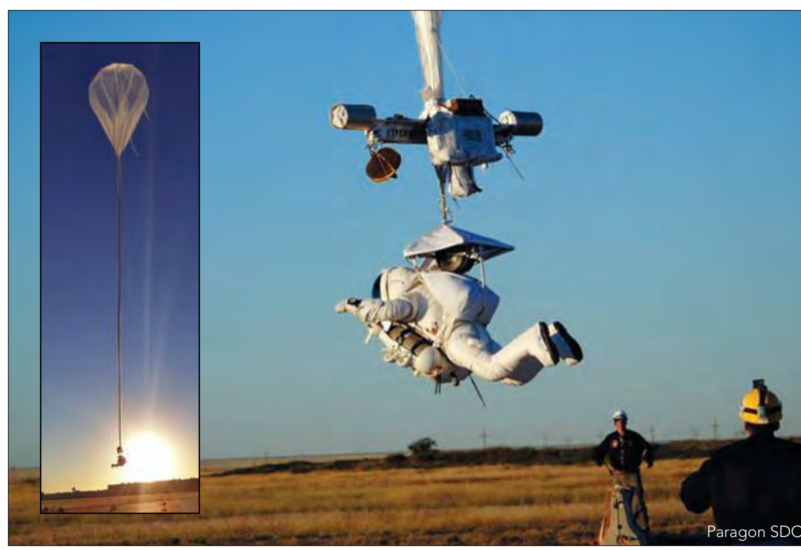
*The **Balloon Systems Technical Committee** supports development and application of free-floating systems and technologies for buoyant flight in the stratosphere or atmospheres of other planets.*

NASA launched three separate **Long Duration Balloon** science missions from Antarctica in a campaign that provided a trove of technical and scientific data for researchers when they concluded in January. The three missions — ANITA-2, SPIDER and COSI — amassed more than 40 days of total flight time. In addition, the NASA Low-Density Supersonic Decelerator was again lifted into the stratosphere by balloon from the Navy's Pacific Missile Range Facility in Kauai, Hawaii. The balloon launched LDSD from a static launch tower to test a potential Mars entry and landing system.

In March, NASA launched an unmanned, pumpkin-shaped super pressure balloon from Wanaka, New Zealand, on a record-setting flight. The balloon, with a volume of 532,200 cubic meters, carried a 2,270 kilogram payload almost entirely around the world in the span of 32 days at an almost-constant altitude of 110,000 feet. NASA commanded flight termination of the balloon in April, bringing it down in the Australian Outback. Regardless, no balloon has ever carried such a heavy payload as far at that altitude and without the need to ballast. The mission was a critical step in qualifying this balloon design as a standard offering by NASA as a platform for the science community. **Raven Aerostar** helped facilitate this groundbreaking NASA flight by providing detailed design support, balloon integration engineering services at the launch site and balloon recovery support in the Outback of Australia.

Raven Aerostar has also been a major contributor to the Google Loon project with balloon design, manufacturing and performance analysis. Project Loon is a Google X Moonshot program with the ultimate goal of providing ubiquitous Internet access over unserved/rural portions of the world where people do not have access to the web. Over the last year, hundreds of Loon test flights have been conducted, compiling thousands of days of superpressure balloon flight at latitudes ranging from the **Arctic to the Antarctic Circles**. Altitude control systems, launch procedures, and flight termination systems were developed and tested using the cavernous blimp hangars at Moffett Field in California.

World View Enterprises, the Tucson, Arizona company that sells balloon rides to near space, this year absorbed the **Paragon StratEx** team that lofted Google executive Alan Eustace for his record-setting skydive in 2014 from an altitude of 135,899 feet. The acquisition included the team's intellectual property. Over three years, Paragon StratEx developed the novel static balloon launch system and the self-contained flight, descent and landing system that made three manned, high-altitude flights in 20 days, culminating with Eustace's record-setting peak altitude of 136,400 feet and his skydive. The flight hardware was scheduled to be delivered this year to the Smithsonian Air and Space Museum. The project included a range of innovations, in particular a novel stabilizing drogue arrangement, called SAEBER, for **Stiff Anti Entanglement Bridle Ejecting Rod**. SAEBER could find wide application for future manned near-space activities. While the balloons used where similar to standard polyethylene scientific balloons, a novel launch method was used to avoid the risks associated with conventional dynamic launch. The balloon was allowed to stand up and Eustace was attached only moments before release, minimizing the considerable risks at launch.



Alan Eustace ascending for a record-breaking high-altitude skydive from Roswell, New Mexico.

CNES, the French space agency, conducted its first scientific **Zero Pressure Balloon** campaign from the Canadian Space Agency's Timmins launch facility in Ontario, Canada, with six flights between August and September. A second campaign included the first flight of an astrophysics gondola called PILOT, for the Polarized Instrument for Long wavelength Observation of the Tenuous interstellar medium.

Near Space Corp. of Tallamook, Oregon, completed several dozen stratospheric balloon test flights for the NASA Flight Opportunities Program. This year's FLOP missions included a test drop of a prototype orbital payload return capsule for Terminal Velocity Aerospace of Atlanta and deployment and performance testing of a specialized high altitude parafoil system for Airborne Systems of Pennsauken, New Jersey.

Advances and setbacks in flight testing

by Bob Curry and Karl Garman

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

This was a year for several significant flight tests for military, commercial, space and technology development programs.

One was the completion of Lockheed Martin's **F-35 Joint Strike Fighter Block 2B** testing. This was the initial demonstration of the jet's war-fighting capability for the U.S. Marines.

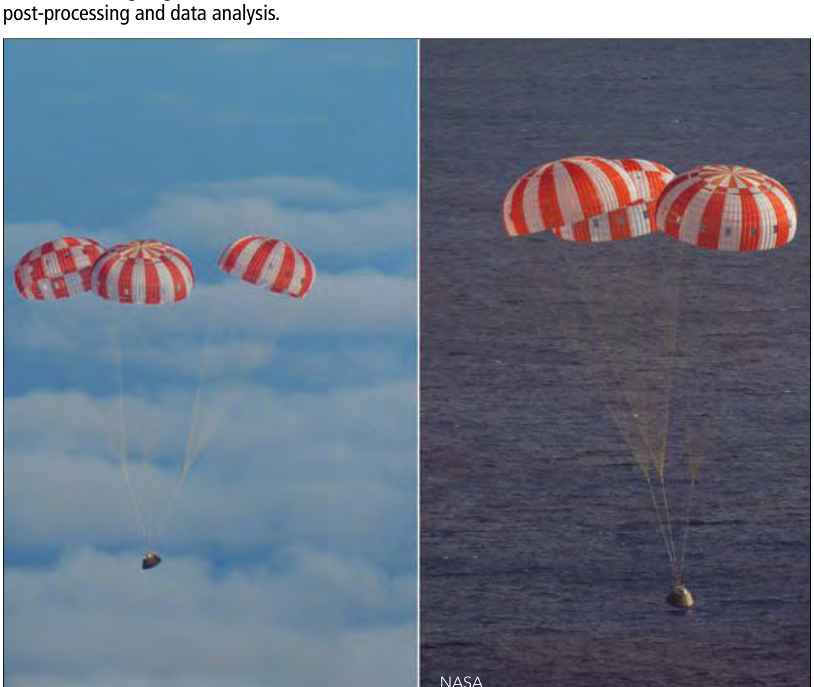
Boeing and the U.S. Air Force continued certification testing for the KC-46A tanker program. The first flight of a tanker-configured KC-46A occurred in September in the Puget Sound area. Flight tests using a 767-2C airframe, which began in late 2014, have accumulated over 150 hours this year.

In a joint effort involving the Air Force, NASA and Lockheed Martin, the auto air-collision-avoidance system demonstrated that it could safely **prevent mid-air collisions** of fighter aircraft during combat training exercises without significantly impeding normal operations.

In the commercial arena, the Bombardier CS100 C Series aircraft, the company's first narrow-body airliner, proceeded through certification testing on a schedule that supports operational service beginning in 2016, thus far accumulating more than 2,250 flight hours.

Following the flight test of NASA's Orion spacecraft on Dec. 5, 2014, the vehicle was returned for detailed post-processing and data analysis. The heat shield, which survived exposure to the extreme conditions of atmospheric reentry, is being used for subsequent ground based testing in preparation for the next phase of flight test operations. NASA's Exploration Mission-1 is scheduled for 2018.

Three main parachutes of NASA's Orion spacecraft helped it descend to Earth after its December 2014 flight test. Since then, Orion has been undergoing detailed post-processing and data analysis.



The NASA Environmentally Responsible Aviation Project, in partnership with the Air Force Research Laboratory, conducted flight tests of **adaptive, compliant trailing edge technology** on a modified Gulfstream G3 aircraft during the first five months of the year. The experimental concept may offer reduced cruise drag and noise and other benefits during landings.

A notable setback took place just after press time for last year's article, when the Virgin Galactic-Scaled Composites **SpaceShipTwo** disintegrated during its fourth powered test flight. The investigative findings will likely drive changes in the interface between technology and public policy for the embryonic space tourism industry.

Several trends are emerging as the community responds to prolonged limited resources, new test technologies, and changing needs. In contrast to historic large-scale, national flight projects, government and industry test programs are pursuing lower-cost flight test strategies. One example is the **X-56A Multi-Utility Technology Testbed.** This modular, low-cost, unmanned configuration enables high-risk parametric experimentation into complex aeroservoelastic technologies necessary to improve flexible aircraft design. The first airframe, developed by Lockheed Martin and the Air Force Research Laboratory, began flying in 2013. A second test vehicle with NASA developed control laws began flying in April. The airplane has flown at negative static margin and a conventional stiff wing in preparation for research with more advanced flexible structures.

The FAA's six unmanned-aircraft test sites have been in operation for more than a year. The need for coordinated system development and flight test activity is expected to grow with increasing industrial interest in unmanned aircraft applications and increasing concerns over interference between unmanned and manned air traffic.

Interest in certain revolutionary aeronautical concepts has also stimulated novel approaches to flight test. Several concepts for electric propulsion appear promising but could also benefit from early and efficient large-scale flight evaluations due to their radical departure from conventional design. For example, NASA's **Leading Edge Asynchronous Propeller Technology** project seeks to study the benefits of distributed electric propulsion with a manned, experimental vehicle. NASA tested full-scale aircraft components at flight speeds on a unique ground vehicle — enabling test conduct while controlling x-plane development costs.

Commercial hybrid airships prepare to get airborne

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.*

Hybrid Enterprises, exclusive reseller for Lockheed Martin's 20-ton capacity **hybrid airship**, LMH-1, announced at the June Paris Air Show that it would start taking orders for delivery as early as 2018. Lockheed said it has completed all required FAA certification planning steps and is ready to begin construction of the first commercial model at its Palmdale, California, facility.

Russia's **Augur RosAeroSystems**, makers of the AU-30 blimp (payload 1/2 ton) intends to complete the first phase of development of its hybrid cargo-and-passenger airship — Atlant-30 (capacity 16 tons) — by December, with tests of a prototype to follow. A larger version, Atlant-100, would carry 60 tons.

TCOM and Logos Technologies demonstrated the capabilities of Logos' Simera wide area motion imagery sensor combined with a TCOM 12M Tactical Aerostat. Targets of interest were located and tracked in real time over a city-sized area, from the system's 360-degree field of view. In October a TCOM aerostat, part of Raytheon's JLENS missile defense system, broke free from its moorings at the Aberdeen Proving Ground and drifted some 150 miles before coming down in rural Pennsylvania. The program has been suspended, pending Army review.

This year, **Goodyear** celebrated 90 years of using airships for advertising, including 60 years of aerial broadcasting. In August, Goodyear retired its GZ-20 blimp, Spirit of America, based in Carson, California, which has carried 30,280 passengers on 8,005 flights since 2002. It will be replaced first by its twin sister, Spirit of Innovation, followed two years later by one of Goodyear's new Zeppelin NT semi-rigids.

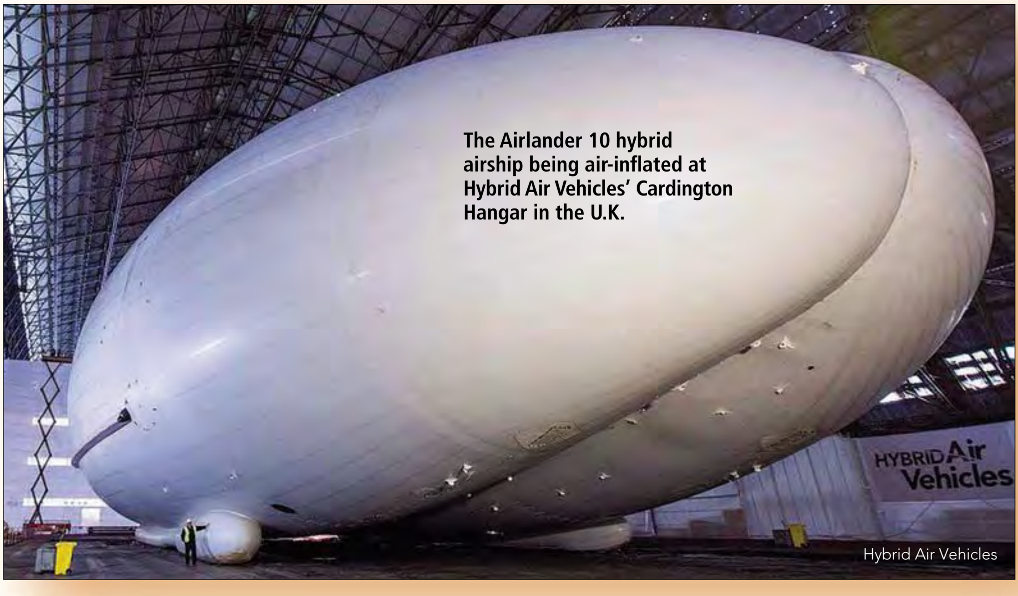
The U.K.'s Hybrid Air Vehicles (HAV) continued to reassemble its 92-meter-long Airlander 10 hybrid airship at its Cardington Hangar in England. The craft was formerly part of the U.S. Army's Long Endurance Multi-Intelligence Vehicle program, and has now been reclassified as a civil aircraft. In 2015 HAV raised money to return it to flying condition, the funds coming from a variety of sources, including $3.4 million from crowdfunding. The company's workforce has increased to 90 as it prepares for a civil flight test program under the direction of the European Aviation Safety Agency. **Airlander 10** is scheduled to fly in the first half of 2016.

In August, Zeppelin Luftschifftechnik GmbH celebrated carrying its 200,000th Zeppelin NT passenger. In the U.S., Goodyear is assembling the second of three NT Zeppelins it ordered in 2001. The craft's first flight is scheduled for spring 2016.

At Aeros Corp. in Los Angeles, design, testing and other development work continues on the ML866 (66-ton payload) **Aeroscraft**. The craft uses a recently patented proprietary buoyancy-control system that allows for vertical takeoff or landing at maximum payload without using external ballast. In March the company sued the U.S. Navy for damage sustained by its Dragon Dream prototype, when the roof of a Navy-owned hangar partially collapsed.

Airship do Brasil, a Brazilian manufacturer of blimps, balloons and other lighter-than-air technology, has made its long-term priority the development of a "classical concept" airship of 30-ton capacity, the ADB 3-30. Applications would include the inspection, maintenance and replacement of electric transmission lines in the **Amazon**. In March the company inaugurated a new headquarters in São Carlos, including a new hangar. It plans to have an intermediary airship, the 50-meter long ADB 3-3 non-rigid, flying in the first quarter of 2016.

In March, U.S. Reps. Tom Rooney (R-Florida) and Brad Sherman (D-California) announced formation of a bipartisan **Cargo Airship Congressional Caucus** to promote cargo airships for commercial and military use.



The Airlander 10 hybrid airship being air-inflated at Hybrid Air Vehicles' Cardington Hangar in the U.K.

Hybrid Air Vehicles

Making freighter conversions more efficient

by Patrick Schultheis

*The **Product Support Technical Committee** advances the quality, technology, and excellence of post-production aviation products and services by providing an international, industry-wide forum for networking and exchanging of best practices.*

After 15 to 20 years of service, most passenger aircraft are replaced with newer models. Some of these planes will get **second lives as freighters**, carrying air cargo for perhaps another 15 to 20 years.

Of the 1,600 freighters in service today worldwide, more than 60 percent are converted passenger airplanes. Converting aircraft provides a lower capital cost option for air cargo operators, and the strategy offers owners and investors an opportunity to extend the lives of assets that would have to be retired otherwise.

The market forecast looks promising for cargo airplanes, which carry half of all airfreight — the other half is transported as "belly cargo" by passenger airplanes. After years of stagnation, air-cargo traffic rebounded in 2014 with an expected growth of 4.5 percent to 4.7 percent annually over the next 20 years, meaning that air cargo traffic could more than double between now and 2035. After a slow start this year, the latest numbers are confirming the predicted growth. Aviation consultancy Air Cargo Management Group released an estimate in May that as many as 3,000 freighters will be delivered over the next two decades, including replacements for more than 1,100 aging freighters too costly to operate. Sixty-five percent of deliveries will be convert passenger jets.

A DHL Airbus A330 freighter is loaded with cargo at DHL's hub in Leipzig, Germany. The majority of freighters in service today are converted jetliners.

Deutsche Post DHL

The Product Support Technical Committee (PSTC) launched the **Special Purpose Aircraft (SPA) subcommittee** in 2002 to identify common issues and standardization opportunities in the conversion market and improve conversion efficiency.

The typical freighter conversion work scope includes the installation of a main deck cargo door, including upper and lower frame shells, main deck loading system, safety barrier net and smoke curtain, as well as systems adaptation, window plugs, passenger-door deactivation and the integration of an optional courier area.

Examples for ideal conversion candidates are the **Airbus A320 and A321**, with over 4,800 aircraft produced to date. A growing number are entering the "conversion window" after 15 to 20 years of service, providing plenty of feedstock for the next 20-plus years.

Still, one of the major challenges of conversion design remains. As Joshua Long, a structural engineer at conversion specialist PACAVI Group, points out: "Any aircraft that is in production for a long time, like the A320 or 737, goes through several service goal and avionic improvements, as well as tweaks in manufacturing to support a more efficient production line. If you add the structural repairs during 20+ years of service, the result is a mixed fleet with many different aircraft configurations."

For conversion design, this means that engineers must deal with significant variances that can only be determined by experience.

"Structure design is especially sensitive to this variability. With new designs you can control both of the mating parts or systems and ensure that they will work. In conversion design, we have to deal with a non-standard, imperfect part, the fuselage, which has changed its size over time", Long says.

This drives either custom engineering for each aircraft, or a design that can accommodate many different changes, an approach that sometimes results in sub-optimal solutions. As production continues, the gained experiences (and the subsequent redesign) are improving the process over time.

Stephan Hollmann, co-founder of the PSTC and chief executive of the PACAVI Group, explains how the company, spearheading an A320 family conversion program, applies a range of practices to improve efficiency: "We are using proven off-the-shelf technology wherever possible. In addition, we will have many components and instrumentation for joint use on both the A320 and A321, like the main cargo door, actuators and the loading system. The aftermarket parts carrying the **Parts Manufacturer Approval** will be certified for both aircraft wherever possible, with a 24/7 AOG (aircraft on ground) program as well as a Continuous Quality Improvement (CQI) program in place to support customers worldwide."

Momentum growing in vertical flight

by Erasmo Piñero

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

Activities in vertical flight continued to gather momentum in 2015.

In July the F-35B program achieved a major milestone: initial operating capability for the U.S. Marine Corps. Prior to the announcement, the Marine Corps had performed **F-35B Operational Test One** (QT-1), consisting of six F-35B short-takeoff-and-vertical-landing variant aircraft with 10 Marine pilots aboard the Navy's amphibious ship USS Wasp, accumulating more than 76 flight hours.

Over two weeks, the Marines and their Navy partners conducted over 100 takeoffs and vertical landings during day and night extended range operations. OT-1 also confirmed aircraft-to-ship network communications interoperability and the suitability of F-35B maintenance support equipment for shipboard operations.

The **Bell Boeing V-22 Osprey** program booked its first foreign sale when Japan announced the purchase of at least five aircraft through the U.S. foreign military sales program. Japan plans to purchase 17 more V-22s. The Japan sale came after V-22 took part in well-publicized humanitarian relief efforts in Nepal and elsewhere, places that until now were accessible only by helicopters and ground transportation.

In late May, Sikorsky Aircraft conducted the first flight of the **S-97 Raider helicopter** prototype, a rigid coaxial rotor and compound helicopter designed to demonstrate the combination of maneuverability, hover ability, range, speed, endurance and survivability requirements set by the U.S. Army Aviation and Missile Research Development and Engineering Center Joint-Multi Role Technology Demonstrator, JMR-TD, program. The **Sikorsky JMR-TD** team conducted the flight at Sikorsky's Development Flight Center in West Palm Beach, Florida. The coaxial counterrotating main rotors and pusher propeller are expected to provide cruise speeds up to 240 knots.

In related news, Lockheed Martin announced the purchase of Sikorsky Aircraft from parent company United Technologies. It is too early to determine how the deal will influence the JMR-TD projects.

Bell Helicopter and Spirit AeroSystems announced that major assembly is progressing on schedule for the Bell V-280 Valor fuselage. The V-280 is a tilt rotor configuration, but the engines do not rotate with the rotors. Bell estimates a forward speed of 280 knots — hence the V-280 designation. Delivery of the first V-280 fuselage to the Bell facility in Amarillo, Texas, took place in September and first flight is expected in mid-2017.

The Sikorsky CH-53K performed its first flight in late October and began a three-year flight-test program. Ground testing of the CH-53K began in April 2014 and is ongoing. The ground tests incorporate the non-flying prototype called the ground test vehicle (GTV). The GTV supplements the CH-53K flying prototype.

VTOL aircraft having conventional wing-borne flight characteristics are seeing a resurgence of interest not seen since the tilt wing research of the late 1960s. This interest is generated by VTOL applications to unmanned aircraft and other small vehicles, and by the potential to use distributed electric and hybrid electric propulsion system architectures that offer quieter, more energy efficient, and more user-friendly performance. A promising concept is NASA's **GL-10 Greased Lightning**. The name is derived from its combustion engine that can burn many types of fuel including biofuel (grease) and the electric propulsion system (lightning).

In early April, the GL-10 completed its first full transition. To date the unmanned vehicle has made 20 conversions to wing-borne flight and back — vertical takeoff, outbound transition, cruise flight as a conventional airplane, inbound transition and vertical landing.

Sikorsky Aircraft

The Sikorsky S-97 took to the air for the first time in a flight from Sikorsky West Palm Beach facilities.

An F-35B Lightning 2 Joint Strike Fighter lands aboard the USS Wasp in May 2015 during operational testing. The fighter jet achieved initial operating capabilities two months later for the U.S. Marine Corps.

U.S. Marine Corps photo by Lance Cpl. Remington Hall

Commercial aviation driving growth

by Venkatesan Sundararajan

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

The global aerospace and defense sectors grew by 1.4 percent to reach revenues of $682.2 billion in 2014, according to Deloitte's annual "Global Aerospace and Defense Sector Financial Performance Study" released in June. This decline from 3.2 percent growth in 2013 and 5.8 percent in 2012 resulted in a slower growth rate than that of global gross domestic product, which grew at 2.6 percent in 2014.

Within those overall figures, global, commercial aerospace revenues grew by 8.2 percent, from $291.2 billion in 2013 to $314.9 billion, indicating that the slowing growth was due largely to **decreased defense spending** in some parts of the world. Mergers and acquisitions rose, resulting in total aerospace and defense sector deals worth $22.3 billion in 2014, slightly above the 10-year rolling average of $21.2 billion. During the first two quarters of 2015, 19 mergers and acquisitions worth $12.4 billion were concluded.

In July, **Lockheed Martin agreed to acquire Sikorsky Aircraft**, a leading military and commercial rotary-wing aircraft maker, for $9 billion. In October, the U.S. Air Force awarded contracts to Northrop Grumman for the engineering and manufacturing development (EMD) and early production of the **Long Range Strike Bomber**. The independent estimate for the EMD phase is $21.4 billion in 2010 dollars.

According to the International Air Transport Association, air travel as of August represented an increase of 7.1 percent compared to a year ago. The 2015 mid-year **IATA Economic Report** forecast for the commercial airline industry projected that total revenue in 2015 will be $727 billion and net profits will be $29.3 billion, compared to actual revenue of $733 billion and a profit of $16.4 billion in 2014.

A **strong market demand for new, fuel-efficient airplanes** is expected to result in $124 billion of commercial aircraft deliveries industry-wide globally in 2015. During the first three quarters of 2015, Boeing delivered 638 jetliners, and Airbus delivered 446 jetliners.

In the general aviation industry, airplane shipments fell 9.1 percent to 1,015 units for the first half of 2015, and airplane billings declined 4.6 percent to $10.4 billion, compared to the same period a year ago, according to the General Aviation Manufacturers Association. Worldwide business jet shipments in the first six months of 2015 totaled 305, a 4 percent decrease from 2014. Rotorcraft shipments decreased, from 502 units to 447 units, and billings were down an estimated 16.8 percent to $1.9 billion for the first six months of 2015.

The **global space economy grew** by 9 percent in 2014, reaching a total of $330 billion worldwide, according to The Space Foundation. The NASA budget for fiscal 2015 was $18.01 billion compared to an actual budget of $17.65 billion for fiscal 2014.

In August, NASA Administrator Charles Bolden informed Congress that NASA is extending its contract with the Russian government to meet America's requirements for crew transportation services valued at $490 million. In January, **SpaceX raised $1 billion** in a financing round with two new investors, Google and Fidelity, that will collectively own just under 10 percent of the company. In 2014, SpaceX was awarded a $2 billion NASA Commercial Crew Transportation Capability contract to transport astronauts to the International Space Station and home, with a goal of **ending U.S. reliance on Russia** in 2017.

Slower growth in China, Japan and Europe were the principal short-term risks to the aerospace industry in maintaining the current earnings growth through the first quarter of 2016. The outlook for the defense sector is mixed, given the declining defense budgets in the U.S., which accounts for 39 percent of the global defense market share. European defense budgets are expected to grow modestly, as are those of emerging markets such as South Korea, India, Indonesia, Saudi Arabia and the United Arab Emirates. The global commercial aviation industry is projected to have robust long-term growth with a need for over 36,000 jet airplanes in the next 20 years valued at $5.2 trillion.

Airbus planned to deliver about 15 A350 XWBs in 2015 to reach its target production rate of 10 aircraft a month.

Airbus

Wrangling over space security

by P.J. Blount and Christopher M. Hearsey

*The **Legal Aspects Technical Committee** fosters an understanding of legal areas unique to aerospace.*

Space security debates continued in the international fora. Russia and China's draft Treaty on the Prevention on the Placement of Weapons in Space remained tabled at the deadlocked United Nations Conference on Disarmament. In July, the European Union invited more than 100 countries to negotiate the terms of a draft **International Code of Conduct on Outer Space Activities**. The meeting was convened at the United Nations headquarters in New York. The discussions quickly bogged down and were reclassified by its chair as a "consultation" after a number of attendees took issue with rules of procedure and forum, and whether there was any mandate for negotiation. The meeting ended with the diplomats agreeing to disagree, politely squabbling about the forum and issues to be discussed.

In January, **SpaceX dropped a lawsuit** it filed in 2014 against the U.S. Air Force after the service awarded a sole-source contract to United Launch Alliance to boost military payloads. SpaceX had argued that the award should have been competitively bid. The company dropped the suit after the Air Force agreed to help complete the military certification of SpaceX's launch vehicles and open future launches to competitive bids.

In July, the NTSB issued its findings on the October 2014 in-flight breakup of **Virgin Galactic's SpaceShipTwo**. Investigators concluded that co-pilot Michael Alsbury, who died in the accident, prematurely unlocked the craft's feathering system, which moves the craft's tail wings in order to slow the craft for its return.

Drones continued to make headlines. While some commercial entities sought public-relations advantage with campaigns built around the technology, numerous commercial passenger, cargo, police, fire and rescue pilots have begun to complain about in-air incidents and near-misses at an exponentially increasing rate, with concerns growing about interference with safe aircraft operations. Some fire-fighting operations have been suspended due to the interference. The FAA proposed new rules for small unmanned aerial systems, which would allow for routine use of craft during daylight hours within line of sight of the operator. Then in May, **FAA Administrator Michael Huerta** indicated that the agency was considering proposing rules that would allow for beyond-line-of-sight operation of drones in the national airspace. The FAA has continued to grant Section 333 exemptions on a case-by-case basis allowing a variety of commercial operations in U.S. airspace. In early August, it announced that more than 1,000 exemptions had been issued.

In the commercial space sector, a broader discussion unfolded this year regarding governmental authorization of commercial space activities. This was precipitated by a December 2014 determination by the FAA informing Bigelow Aerospace that the agency would work to protect private sector assets on the moon and provide a safe environment for **Bigelow** and other companies to operate without fear of harmful interference from authorized entities. The determination was issued in response to a "payload review request" made by Bigelow Aerospace related to its plans to place a space habitat system on the moon. Subsequently, the FAA's Commercial Space Transportation Advisory Committee endorsed the FAA's role in helping to define a zone of non-interference for commercial space operators.

Manfred Lachs Space Law Moot Court Competition

University of Mississippi students address the panel at the Manfred Lachs Space Law Moot Court Competition in Washington, D.C. Space security has proven to be a contentious issue at the United Nations.

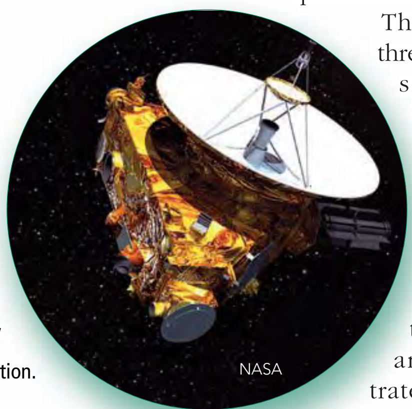
Aerospace news captures the public's attention

by R. Steven Justice and Bradley A. Steinfeldt

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

Aerospace technology is so much a part of the fabric of our lives that its benefits go unnoticed by most of us, even by those within the industry.

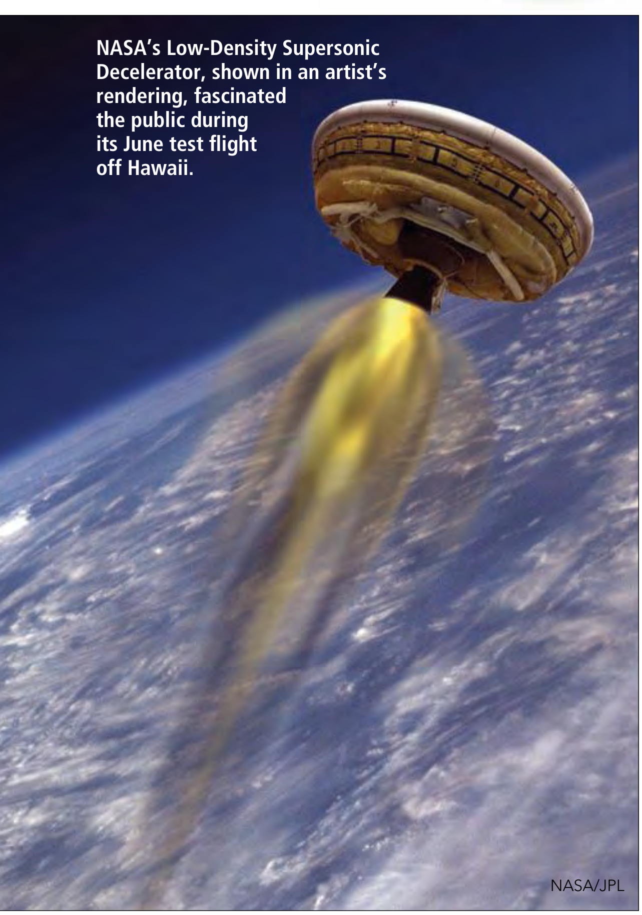
Sure, we might think about satellite technology when we use **GPS-enabled navigation** systems in our cars or when we access satellite weather images. But how many of us think "aerospace" when we buy fruit in the grocery store in the dead of winter or when we buy the latest must-have children's Halloween costume? Those items are, of course, flown from overseas by air cargo using aerospace technology.



New Horizons, shown in an artist's rendering, is credited with stirring interest in STEM education.

NASA

The year saw three major news stories that captured the notice of the general public. Two showed the power of technology to inspire and another illustrated the challenges sometimes inherent in introducing new technologies into society. Three major news stories captured the public's attention in 2015 by highlighting how technology can inspire people — as well as how it can stir fears and trepidation.



NASA's Low-Density Supersonic Decelerator, shown in an artist's rendering, fascinated the public during its June test flight off Hawaii.

NASA/JPL

Nothing in 2015 captured the trepidation aspect more than the **explosive growth** of the commercial unmanned aircraft market. Early uses of unmanned aircraft in the commercial arena include film production, agriculture, infrastructure inspection, and possibly even package delivery. The Aerospace Industries Association notes that "with countless benefits it is not surprising that society is waiting to fully utilize these systems." But society is not waiting. Technology has now made small electric, unmanned aircraft available to almost anyone who wants one. The FAA estimates that almost 1 million small unmanned aircraft will be sold in the U.S. in 2015.

This proliferation of "drones" is concerning to segments of the public worried about safety and the erosion of privacy. In July, a Kentucky man was reportedly arrested after he shot down a neighbor's drone that he believed was hovering over his yard taking pictures. A local judge later dismissed the case, ruling that the drone represented an invasion of privacy. In response to concern by their constituents, over 30 state legislatures have either passed or contemplated **laws on "drone" use**, which could deter the growth of this new market. President Obama directed the Commerce Department's National Telecommunications and Information Administration to develop privacy, transparency, and accountability rules for both government and public drone use.

On a more positive note, NASA's New Horizons spacecraft, which had been traveling for a decade in relative obscurity, burst on the scene with a flyby of the dwarf planet Pluto in July. In an age when spaceflight seemed to lose its luster with the public, New Horizons attracted weeks of coverage by all the major news outlets and numerous blogs.

A major benefit of the media coverage of New Horizons was to inspire a new generation of people to pursue careers in STEM, science, technology, engineering and math. One article, headlined, **"The Women who Power NASA's New Horizons Mission to Pluto,"** quoted a deputy project scientist who said "girls will be inspired to be scientists and boys will grow up to be 'gender blind,' seeing women in science as the norm."

Closer to Earth, NASA's Low Density Supersonic Decelerator fascinated people in June with its resemblence to a **"flying saucer"** during a flight off Hawaii. A key technology for future Mars missions, the LDSD project's goal is to develop entry, descent, and landing technology that is capable of landing 2,000 to 3,000 kilograms on Mars through the use of new drag devices — larger parachutes and supersonic inflatable aerodynamic decelerators.

The LDSD test flight in June drew coverage via Livestreams, Twitter, blogs, Instagram and Reddit, in addition to newspapers and television, demonstrating the public's connection to this new and exciting technology.

NASA airspace technology demonstration accelerates NextGen

by William C. Johnson

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


NASA's FutureFlight Central is a full-scale airport-operations simulator located at NASA's Ames Research Center in California.
NASA

This year, NASA's **Airspace Technology Demonstration–1** (ATD-1) project began working with an industry team to develop a prototype of new airborne automation software tools for use on commercial aircraft and continued efforts to support the successful technology transfer of new ground automation software tools for use by the FAA. The combined results of these efforts will be new ground-automation capabilities known as **Terminal Sequencing and Spacing** (TSAS) and airborne automation capabilities known as Interval Management (IM). The end state for both capabilities is technology readiness level 6 built on vendor platforms to demonstrate the capabilities of an integrated arrival solution that can bring benefits to airspace users and airspace managers once implemented.

This year, TSAS passed the FAA's final investment decision, a milestone that paves the way for implementation by 2019. IM also passed the FAA investment analysis readiness decision, with the final investment decision planned for 2017.

Reaching this point in the ATD-1 project came with a number of significant challenges, among them integrating three research teams — one for each technology — from two different coasts, each with different assets available in their local facilities. Another challenge was making incremental advances toward products that work together to achieve improved efficiency in the air-traffic system even as stakeholder requirements were still being written.

Systems engineering was recognized as a critical element of the project planning. The greatest challenge in selecting a suitable approach originated from a NASA desire to provide maximum value to the stakeholder community, while the stakeholder requirements were still being developed within the community. Significant effort was made to collaborate with various stakeholders. Given the uncertainty associated with stakeholder requirements, NASA adopted the **agile systems engineering** approach to provide flexibility in addressing an extended requirements definition phase from the community. With agile systems engineering, high-bandwidth communications within the team is necessary, and this must be extended to key stakeholders during the requirements definition phase. This continual interaction with key stakeholders also assisted NASA in anticipating changing requirements from the community and responding to them with increased agility.

Meanwhile, integration work began in three labs at NASA Langley and NASA Ames research centers to prepare the integrated tools for test and evaluation. A baseline test environment was established and implemented in the labs using tools developed from both NASA centers. The result is a world-leading capability to simulate integrated air-traffic-management operations representing air traffic and aircraft capabilities.

Following that, NASA conducted more than 20 integrated simulations to assess the concept and tools. The technology transfer process included a series of incremental handoffs to the FAA comprised of all documentation, software and prototypes developed by ATD-1, as well as active participation on FAA technical and investment decision teams. In addition, prototyping the capabilities into vendor platforms provided a means to transfer the technology to industry, and participation in standards development with the FAA-chartered RTCA was essential to aligning the avionics prototypes with the community.

With the completion of the technology transfer of TSAS to the FAA in late 2015, the **Interval Management** development remains to be completed with industry partners — Boeing, Honeywell and United Airlines — before ATD-1 is completed at the end of fiscal 2017.

Based on the successes of the ATD-1 project, other demonstrations have been created to address the extremely complex integrated arrivals, departures and surface operations, and traffic flow management operations for en-route and oceanic operations. These new sub-projects have taken the lessons learned from ATD-1 and established similar systems engineering processes to continue providing value to the community.

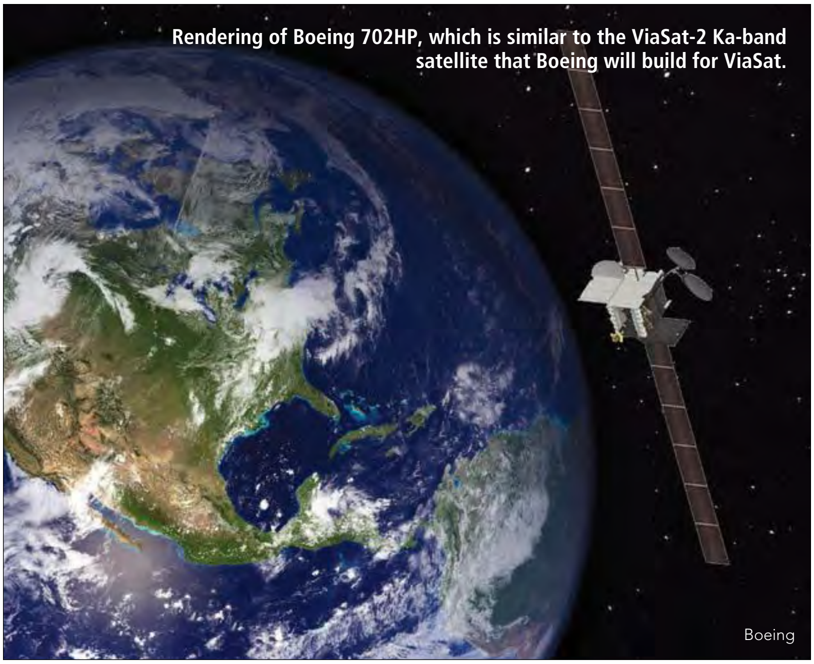
Profound transition continues for satcom

by Tom Butash, Joe Pelton and Roger Rusch

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

The satellite communications industry is undergoing great transition, like much of today's global economy. Technology is offering new approaches that are disrupting business as usual. Time will tell whether this will spawn successful new businesses or lead to overcapacity.

Efficient launch services are key to the SATCOM industry. **SpaceX's Falcon 9** and Falcon Heavy provide a new, essential capability, with 18 successful launches and 67 more scheduled through 2018 with a launch tempo of two launches a month during 30 months of this period — an unprecedented launch rate for a single launch system. However, a June Falcon 9 failure has delayed the inaugural Falcon Heavy flight until next spring, after Falcon 9's successful December launches of Orbcomm and SES commercial communications satellites.


Rendering of Boeing 702HP, which is similar to the ViaSat-2 Ka-band satellite that Boeing will build for ViaSat.

Boeing


SSL

Artist's concept of the Jupiter 2/EchoStar 19 satellite, which will be launched in 2016.

New launch competitors include the Russian Angara, Ariane 6, Japanese H-3, and Orbital ATK's Antares as well as established systems. For small satellite constellations, new options are planned for 200 kilogram-class satellites, including Virgin Galactic's Launcher One, and the Swiss Space Systems S3 spaceplane. The late August Russian Proton M launch of the third **Global Xpress satellite** allows Inmarsat to begin operation of the first global coverage broadband GEO constellation by year end.

Another big story is the ongoing surge in Ka-band high-throughput satellites and expansion of conventional C and Ku-band satellite payloads. Intelsat plans to launch eight **EpicNG satellites** over the next three years to add about 900 net transponders — a 40 percent increase to its 2,200 on-orbit transponders. SES of Luxembourg plans to add a comparable supply. An even greater surge is underway in HTS for consumer broadband or Internet access, led by ViaSat-2 and Hughes' Jupiter 2/EchoStar 19 satellites to be launched in 2016. Overall, the industry plans to quadruple the communication throughput supply between 2010 and 2017.

The elasticity of demand and new pricing levels are big questions intriguing the industry. Other key questions include when Ka-band will become congested and when Q/V- and W-bands can be utilized to further increase capacity. The European Space Agency's Aldo Paraboni Q/V Band Payload aboard Alphasat continued to collect experimental propagation data this year to help pave the way to deployment.

The new **O3b equatorial middle-Earth-orbit constellation** optimized for Internet is now operational. This project, backed by SES, Liberty Media and Google, among others, is only the first step. Silicon Valley is seeking to provide ubiquitous worldwide broadband access. Dominant Internet companies like Facebook, Apple, Google, Amazon and Qualcomm and innovative space systems companies such as SpaceX are investigating at least 11 constellations consisting of hundreds or thousands of satellites, envisioned to cost as little as $1 million each on-orbit. Also under consideration are balloon and unmanned aircraft-based global Internet systems seeking new economies of service. It remains to be seen whether these new visionaries can achieve what was unaffordable a little more than a decade ago.

It has long been a dream to build satellites quickly and adapt hardware on-orbit to changing markets. In the past such flexibility came at a high cost and took longer to develop, but the first steps are being taken today. Intelsat is deploying its EpicNG satellites with next-generation service to begin in 2016, while **Eutelsat has commissioned the Quantum satellite**. Other R&D projects are focusing on greater flexibility in future retrofits.

Satellite orders remain strong with 17 orders as of early November, although slightly off 2014's pace of 25 by year end. Growth in revenues for 2015 is projected to be somewhat down from the 4 percent revenue growth recorded last year.

Old processors guide new space explorations

by Rick Kwan

*The **Computer Systems Technical Committee** advances the application of computing to aerospace programs.*

Some of the biggest space science achievements in 2015 were delivered by processors designed two decades ago, even as new computing architectures and standards this year point toward new strategies for exploration.

NASA's Cassini spacecraft continues to return images and science data from Saturn and its moons. Its brains are a set of seven **Generic VHSIC Spaceborne Computer** (GVSC) flight computers born from the Pentagon's Very High Speed Integrated Circuit, or VHSIC, program of the 1980s. GVSC is a radiation-hardened 16-bit processor for the U.S. Defense Department's MIL-STD-1750A instruction set.

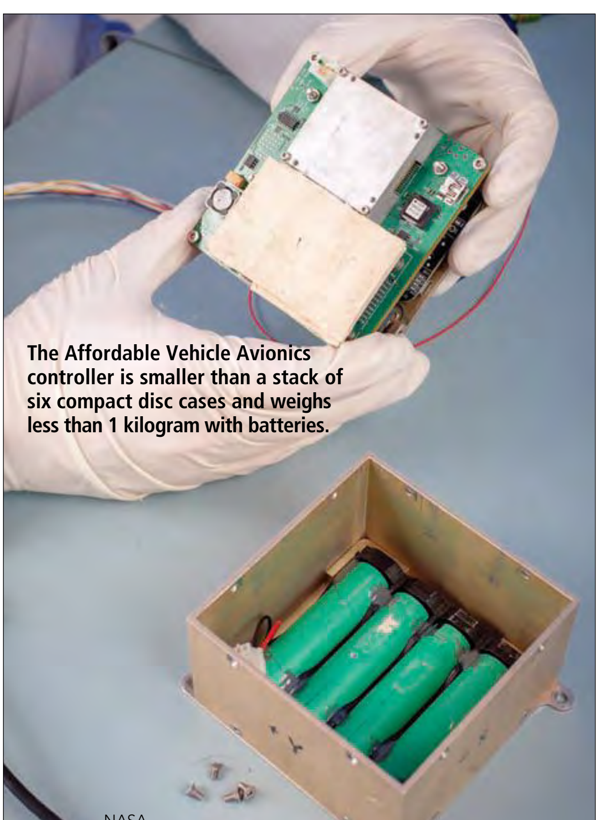
New Horizons zipped by Pluto and Charon and other moons in July, revealing an unexpectedly complex terrain. The spacecraft uses a **MIPS R3000 processor**, popular with a spectrum of devices from game consoles to servers in the 1980s and 1990s, and widely studied in computer architectures courses. Announced in 1996, the Mongoose-5 is a rad-hard version of the MIPS R3000, and was used on several NASA missions before being launched on New Horizons in 2006. New Horizons continues its data dump from Pluto while speeding along toward its next Kuiper Belt target. The Cassini will reach a fiery end in September 2017, when the craft descends into Saturn's atmosphere to deliver a final burst of scientific data. In the inner solar system, the computing workhorse continues to be the RAD750 processor, the rad-hard adaptation of the PowerPC 750. It's also aboard Juno, the NASA New Frontiers probe now on its way to Jupiter.

Earlier this year, the VITA 78 SpaceVPX Systems standard was recognized by the American National Standards Institute as the ANSI/VITA 78.00-2015 open standard.

At the opposite end of the spectrum are short-term low-cost missions in low Earth orbit. With protection from the Earth's geomagnetic field, more effort is placed on qualification of commercially available parts, both for small satellites and small launch vehicles.

Tyvak Nano-Satellite Systems, a company formed in Irvine, California, by some of the creators of the cubeSat standard, provided its Intrepid board for this year's Lightsail-A mission. The board is a Linux-based system using an ARM9-based processor for both command and data handling and electrical power. A variation of the board is expected for small launch vehicles.

Engineers at NASA Ames announced the **Affordable Vehicle Avionics package**, a modular avionics system for small launch vehicles. It uses a Linux-based ARM Cortex-A8 system with real-time extensions, and a variety of sensors. They hope to test it as a non-guiding payload on suborbital "open loop" flights by the end of 2015, and follow those with flights where it will actively guide a launch vehicle.



The Affordable Vehicle Avionics controller is smaller than a stack of six compact disc cases and weighs less than 1 kilogram with batteries.

NASA

The computing world is being rocked by the **Internet of Things**, a notion that objects ranging from wearable devices to autonomous vehicles can be linked to the Internet. To accomplish this, communication and computing cores are being merged into a system on a chip, which then sits on a board with sensors and actuators. The communications link can be Wi-Fi, Near Field Communication (typically 10 cm) or a software-defined radio capability. Doing so raises the specter of mesh networks, the subject of IEEE standards such as 802.11s and 802.16. The Internet of Things has also prompted renewed development of real-time operating systems, this time focused on small devices. Commercially, billions of U.S. dollars are at stake, attracting lots of players, and likely to result in new autonomous device interfaces that the aerospace industry will have to decide how to handle.

Securing communication channels for unmanned aircraft

by David W. Matolak

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

The air-ground communication channel is commonly considered to be fairly benign in terms of risk of disruption, particularly in comparison to terrestrial channels such as those of cellular transmissions, in which obstructions and multiple signal paths can severely attenuate and distort transmitted signals.

In fact, hundreds of journal and conference papers have been published in the past 30 years on **cellular channel characteristics**, compared to a few dozen papers over 60 years on the air-ground channel. This difference is due to the historical practice in civil aviation of using ground sites in open, clear areas, with antennas on tall towers, and to the traditional narrowband nature of AG signals.

For unmanned aircraft, location of ground sites in open areas with tall antenna towers may not be guaranteed, and (as has also happened to commercial communication systems) data rates and consequently signal bandwidths are increasing. Hence traditional simple narrowband models for the air-to-ground channel will not always be sufficient for unmanned craft. Flight dynamics also differ from those of piloted aircraft, making the phenomenon of airframe shadowing, or signal blockage from the aircraft itself, more significant.

NASA engineers raise a communications tower that transmits data to the NASA S-3 Viking research aircraft.

NASA

The FAA made progress in 2015 toward integrating commercial unmanned aircraft into the National Airspace System. In July, RTCA, an FAA-chartered company that helps set aviation standards, established preliminary minimum operational performance standards for unmanned aircraft. The final version of the minimum standards is planned for early 2016. The **University of South Carolina** is working with NASA Glenn Research Center in Ohio on part of an unmanned-aircraft integration project; the initial area of investigation is air-to-ground channel measurements and modeling. This year, the project specifically produced models for airframe shadowing effects and statistical distributions of excess path loss, the latter of which were used by RTCA.

NASA

NASA researcher Jim Griner sits inside S-3 Viking research plane as he coordinates testing of a prototype radio that will help link pilots on the ground to their unmanned aircraft.

Specifically, a research team from the university, NASA and **Berkeley Varitronics Systems** developed a customized dual-band, single-input/multiple-output wireless channel measurement system or sounder for measuring and modeling the channel. This sounder outputs signals in the two bands recently allocated by the International Telecommunication Union for unmanned aircraft operation: an L-band signal of bandwidth 5 megaherz, centered near 968 MHz, and a C-band signal of bandwidth 50 MHz, centered near 5.06 GHz. These signals employ spread spectrum signaling to enable complete estimation of the time-varying air-to-ground channel's response, simultaneously as received by two antennas in each band.

Since NASA began the measurement campaign in 2013, flight tests have been conducted for a variety of scenarios: over sea and fresh water, over hills, mountains and deserts, and over urban and suburban areas. Test data will allow development of accurate, validated, wideband **AG channel models** for these environments. All told, the NASA campaign collected nearly a third of a billion channel responses in these environments, making this the most comprehensive AG channel measurement campaign in history. The data is now being analyzed.

From these measurements, we are developing channel models for propagation path loss, or attenuation, small-scale (multipath) fading and dispersion, airframe shadowing, and correlations among the signals at different frequencies and different antennas. These models will be used to assess performance of candidate AG radio technologies, and can also be used to evaluate future advanced signaling schemes. Ultimately, the models will be used, along with radio technology models, to evaluate complete AG networking performance for unmanned aircraft. This year, models for the over-water and hilly/mountainous settings were finished, and remaining models are nearing completion.

Results from this work have been published in numerous conference papers and NASA reports, and journal papers are in preparation. Results have also been presented to RTCA, and to the **International Civil Aviation Organization**, for use in international standards development for unmanned aircraft. Future work may include AG channel model development for very small, and low-altitude unmanned aircraft.

Outlining paths to safer and more reliable aerospace systems

by Elad Kivelevitch

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

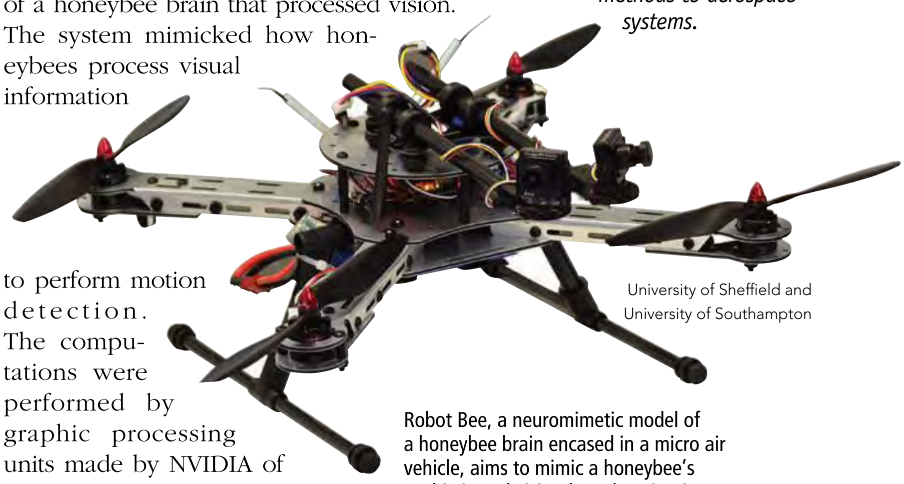
The Intelligent Systems Technical Committee this year drafted a "**Roadmap for Intelligent Systems in Aerospace**" recommending investments by government, academia and industry in an effort to produce aerospace systems that are more adaptive, reliable, secure, safe, cost-effective, trustworthy and cooperative. Development areas include autonomy, computational intelligence and adaptive control. The draft was presented to 180 participants at the AIAA Intelligent Systems workshop in August seeking feedback.

Loss of control is a leading cause of fatal aircraft accidents, and many of those accidents are precipitated by a pilot losing awareness of the state of the aircraft. The Intelligent Systems Division at NASA Ames Research Center in California is teaming with the German Aerospace Center to develop new predictive, assessment and alerting technologies to enable flight displays that depict the current and future state of the aircraft. New display features and alerts developed from this work were installed this year at NASA's Langley Research Center in Virginia so commercial airline pilots can try the features and provide feedback. The features and alerts were evaluated previously in the Advanced Concepts Flight Simulator at NASA Ames. Commercial airline crews flew multiple problematic approach and landing scenarios, with results showing the potential to improve situational awareness.

Researchers from NASA Ames and Oklahoma State University are working on an online adaptive Multi-Objective Optimization (MO-Op) flight and wing shaping control technology that could enable aircraft to adapt themselves to changing mission requirements and flight conditions. The goal is to achieve simultaneous control requirements including adaptive drag optimization, load alleviation, modal suppression, and conventional flight control. This effort is aimed at reducing flight cost in commercial airliners. The **adaptive drag optimization strategy** includes using distributed sensors for drag optimization. NASA Ames researchers at AIAA's 2015 SciTech Forum reported that multi-object flight control simulations show a drag reduction of 4-6 percent, which is consistent with previous wind tunnel data.

In an effort to enable safe and efficient unmanned aircraft operations in low-altitude, uncontrolled airspace, NASA's Unmanned Aerial System Traffic Management system was tested in August at Crows Landing, California. UTM will provide airspace management, flight planning and monitoring, separation assurance, collision avoidance and weather prediction for unmanned aerial system operators to deconflict and monitor operations in the lower altitudes. UTM leverages the lessons learned from the well-established air traffic management system and future plans for the FAA's NextGen Air Transportation System. NASA's goal is to demonstrate how the UTM enables safe low-altitude and unmanned-aircraft operations within five years. The goal over the next 10 to 15 years is to enable the safe operation of all low-altitude airspace operations given the dramatically increasing number of aircraft in this regime.

In the U.K., the University of Sheffield and the University of Sussex achieved a milestone this year in the **Green Brain Project** when they flew a quadcopter using a neuromimetic model of a honeybee brain that processed vision. The system mimicked how honeybees process visual information to perform motion detection. The computations were performed by graphic processing units made by NVIDIA of California. Additional research focuses on detection, classification, and learning in the olfactory pathways of the honeybee. This research not only sheds light on the honeybee brain and basic cognition, but also develops robust and adaptable guidance and control systems for MAVs so they can survive in a complex world.



University of Sheffield and University of Southampton

Robot Bee, a neuromimetic model of a honeybee brain encased in a micro air vehicle, aims to mimic a honeybee's sophisticated vision-based navigation.

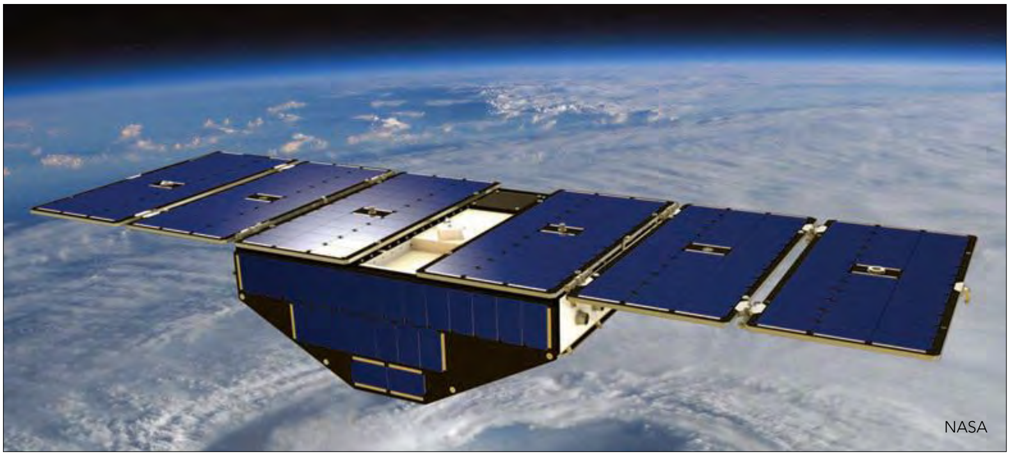
The **V-FASTR** (Very Long Baseline Array-Fast Transient) detection system surpassed 200,000 detections. V-FASTR searches for short radio transient sources of less than one second, and it employs a machine classifier trained on human-labeled events to determine whether each detection was caused by an artifact, a pulsar, or an unknown source. The latter category is of most scientific interest, with the potential for new discoveries. To date, the system has processed nearly 200,000 detections, including 40,000 pulses from known pulsars, and continues to listen for new detections of novel scientific interest. This system is a collaboration between Curtin University in Australia, the National Radio Astronomy Observatory and NASA's Jet Propulsion Laboratory in California.

Different paths to sense-and-avoid technology for unmanned aircraft

by Timothy L. Howard, Domenico Accardo and Wei-Jen Su

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

Sense-and-avoid (SA) technology for unmanned aircraft that will fly in civil airspace continues to advance, with several different onboard and ground-based approaches currently being developed and tested. Onboard SA systems typically use radar plus electro-optical (EO) sensors, often augmented by automatic dependent surveillance-broadcast location and identity transmissions. These systems require significant investments in sensor fusion techniques. This year, for example, development work on the FAA's **ACAS Xu** system (Airborne Collision Avoidance System for Unmanned Aircraft) capitalized on the proof-of-concept SA system tested in late 2014 on NASA's Ikhana, a civil version of the Predator-B. This proof-of-concept system incorporates air-to-air X-band radar plus ADS-B. Honeywell also provided an integral fusion algorithm for combining data from multiple sensors. The system will help pave the way for ACAS Xu to be used by the UAS community.



The Cyclone Global Navigation Satellite System will use eight satellites and a novel multipath technique to provide accurate, frequent measurements of hurricane and tropical-storm winds.

Others involved in this space include the Air Force Research Lab, which is working with Defense Research Associates to develop an SA system that doesn't require aircraft modification. This system uses passive EO sensors to detect, identify, and track both cooperative and non-cooperative aircraft. Also, Sikorsky has been working on an autonomous helicopter fly-by-wire system since 2013, with flight trials continuing. This system includes **LIDAR** and other sensors for avoiding obstacles and finding safe landing spots. The company is working on a similar system to help alleviate aircrew workload on manned craft.

Europe is also heavily involved in this technology. **Alenia Aermacchi** reported in June that it completed trials of a collision avoidance system under the Mid-air Collision Avoidance System program sponsored by the European Defense Agency. The MIDCAS program involves a number of European countries and companies and includes on the aircraft EO, radio, infrared (IR) and radar sensors.

The New Horizons spacecraft completed its flyby of Pluto in July. The spacecraft's **Long Range Reconnaissance Imager** delivered some striking images, with more to come as data are received and processed in coming months. Almost unheralded aboard New Horizons is the debut of the first student-built experiment on any interplanetary spacecraft, the Venetia Burney Student Dust Counter. Built by University of Colorado students, the instrument has already surpassed the previous distance record of dust measurements of 18 astronomical units set in 2010. It is giving the first look at the density of dust in the outer solar system, which likely originates at least in part from collisions between minor bodies, and will help scientists understand dust sources and transport mechanisms out to 40 AU.

NASA has begun building a multisatellite mission, the **Cyclone Global Navigation Satellite System**, to provide surface wind measurements of hurricanes and tropical storms. CYGNSS comprises eight microsatellites to be launched together on a Pegasus rocket in late 2016. The satellites will use a multipath, multi-sensor measurement technique that receives GPS signals along both direct and ground-reflection paths. The combined motions of the CYGNSS and GPS satellites will allow measurements of wind speed. The system will be deployed with satellites distributed around Earth to give revisit times of around 12 minutes. This will allow for updates of tropical wind speeds several times per day, as opposed to once every few days with current satellites.

NASA has also given the green light to construction of the Solar Probe Plus. The spacecraft, to be developed by the **Johns Hopkins Applied Physics Lab**, will be the first to approach the Sun within about 6 million kilometers. It will host instruments for particles and fields as well as a wide-field imager for close-up studies of the solar corona. The imager will allow scientists to make 3D coronal images, giving a much better view of internal motions such as clouds and shocks.

Guarding against cyberattacks and software glitches

by Ella Atkins, Sam Adhikari and Susanne Strege

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

Software continues to be a core component of aerospace systems with several advancements over the year.

In March, the Innovative Technology Partnerships Office at NASA's Goddard Space Flight Center in Maryland released the **core Flight System** application suite. The cFS is a platform and project-independent, reusable software framework and set of reusable software applications. The cFS architecture incorporates a dynamic run-time environment, layered software, and a component based design. These key aspects make cFS suitable for reuse on numerous NASA spaceflight projects and/or embedded software systems at a significant cost savings. cFS is in use by multiple NASA Centers as well as industry. The complete cFS open-source framework is now available for public download via the core Flight System page of the NASA Goddard website.

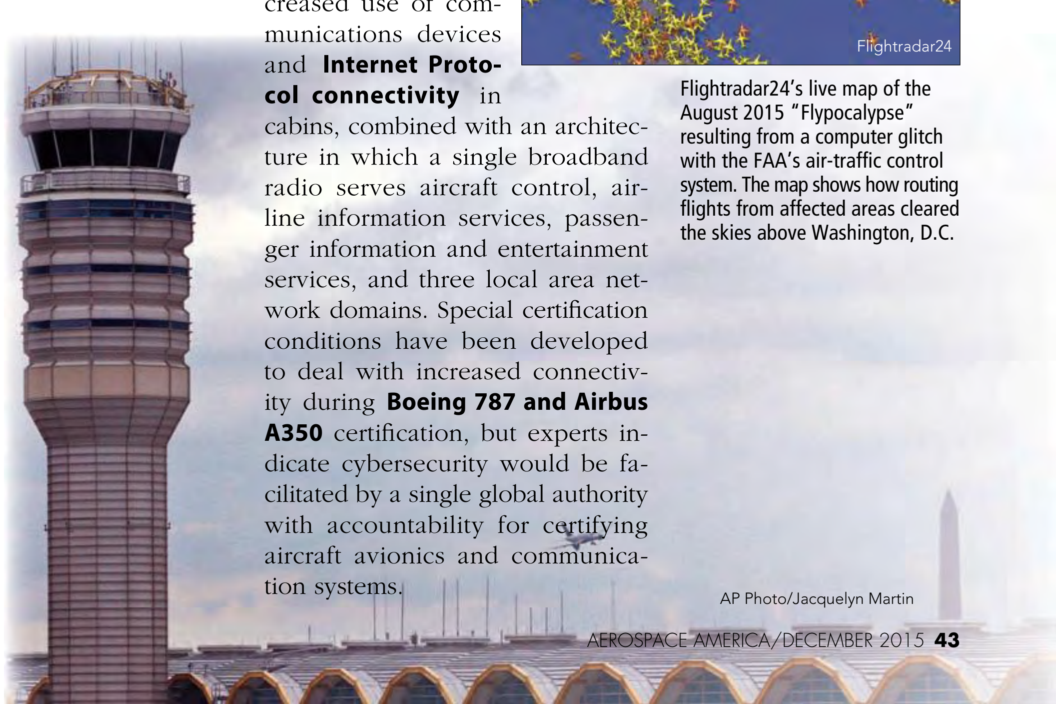
Sysoft Corp. in Whitehouse Station, New Jersey, this year developed a camera-based tracking system that can achieve accurate in-air localization for unmanned and manned aircraft in low visibility conditions. The tracking system will support close-proximity unmanned aircraft formation flight, enabling autonomous air-to-air refueling and energy savings due to reduction in induced drag. Real-time localization using the vision data supports improved tracking errors within 5 percent of a wingspan both horizontally and vertically. Real-time image processing with color-based segmentation using K-Means clustering provides computational features that are validated against large datasets using big data analytics.

Flightradar24, which operates a website displaying real-time locations for thousands of aircraft, in November provided Egyptian investigators and the French BEA agency with the air traffic data it received from the Metrojet Flight 9268 aircraft that exploded over the Sinai Peninsula. Flightradar24 collects data from approximately 7,000 Mode S transponders and automatic dependent surveillance — broadcast receivers around the world, and receives supplemental 5-minute-delayed FAA data for the U.S. and Canada. FlightAware publishes Mode S and ADS-B tracking data in addition to receiving more than 50 government air traffic and private datalink feeds. In 2014, it began offering a low-cost means for a user to turn a Raspberry Pi processor into a PiAware ADS-B ground station.

While software advances continue to enable revolutionary progress in aerospace, software and data entry errors also caused air travel problems in 2015. In August, an air traffic tracking computer system glitch resulted in a period of flight delays that was quickly dubbed "**Flypocalypse**." Planes were not allowed to fly near the busy Washington, D.C., region over an extended stretch during the day, which created a domino effect of more than 2,000 flight delays and hundreds of cancellations. In February, United Airlines mistakenly allowed several thousand passengers to book first-class trans-Atlantic flights for as little as $51 due to a currency-exchange rate error by a third-party software provider.

In cybersecurity, the aviation industry made significant progress this year. To prevent network-based cyberattacks, a team consisting of Boeing, National Information and Communications Technology Australia, Rockwell Collins and Galois is rewriting drone software to isolate from the outside world all communications between a ground station and the aircraft. The work is being performed under the DARPA High-Assurance Cyber Military Systems program. While hack-proof technology cannot compensate for faulty software, system failures or operator error, it can prevent a malicious party from taking control. Cybersecurity challenges are also present for manned aircraft due to increased use of communications devices and **Internet Protocol connectivity** in cabins, combined with an architecture in which a single broadband radio serves aircraft control, airline information services, passenger information and entertainment services, and three local area network domains. Special certification conditions have been developed to deal with increased connectivity during **Boeing 787 and Airbus A350** certification, but experts indicate cybersecurity would be facilitated by a single global authority with accountability for certifying aircraft avionics and communication systems.

Flightradar24's live map of the August 2015 "Flypocalypse" resulting from a computer glitch with the FAA's air-traffic control system. The map shows how routing flights from affected areas cleared the skies above Washington, D.C.



AP Photo/Jacquelyn Martin

Grease and trash feed advances in biofuels

by Marty Bradley, Gary Dale and Keiichi Okai

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

Many organizations, large and small, continue to research and test electric and hybrid electric aircraft.

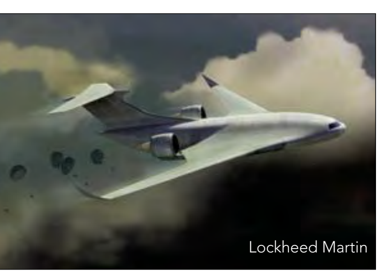
In July, Solar Impulse 2 broke records after making a four-day, 22-hour solo flight from Nagoya, Japan, to Hawaii.

In July, the **Airbus E-Fan** electric aircraft flew across the English Channel. Also, the Japan Aerospace Exploration Agency completed flight tests on an electric propulsion system for aircraft. JAXA demonstrated how the system's unique power regeneration function can serve as a substitute for traditional air braking during descent and how the redundant motor system ensures better fault tolerance.

In the U.K., a project led by the University of Cambridge and sponsored by Boeing tested an aircraft with a parallel hybrid engine — one that can recharge its batteries in flight.

In April, NASA flew its 10-engine, battery-powered Greased Lightning 10 unmanned aircraft, demonstrating transition from hover to wing-borne flight and back to hover for landing.

Progress on alternative fuels continued in 2015. United Airlines announced a $30 million investment in **Fulcrum BioEnergy**, a California company that has developed and certified a technology to convert municipal trash into fuel blendable with traditional fuels. Also, FedEx has agreed to purchase 3 million gallons of renewable jet fuel annually over eight years from Red Rock Biofuels of Colorado.



Lockheed Martin's hybrid-wing-body concept airlifter is designed to burn 70 percent less fuel than the C-17.

A Japanese consortium has established a five-year road map to develop sustainable aviation biofuel by the 2020 Summer Olympics in Tokyo. In addition, Boeing and the Commercial Aircraft of China, COMAC, opened a demonstration facility for turning used cooking oil into sustainable aviation biofuel. China is estimated to generate enough of this oil to produce 500 million gallons of biofuel annually.

The Air Force Research Laboratory is advancing biosensor technology for early-warning detection, monitoring and risk assessment of bio-deterioration in the Defense Department's fuel systems.

Boeing and its partners continued the ecoDemonstrator program's multi-year effort to accelerate new technologies and methods for greener aviation. Active flow control is one of 18 technologies tested on the ecoDeomonstrator 757. The technology could reduce tail size by 17 percent, reducing tail weight and also drag by about 0.5 percent. These improvements would cut an airplane's fuel use and carbon emissions.

On the right wing of the ecoDemonstrator, NASA tested bug-phobic coatings that would reduce the residue left by bug strikes, with the goal of enabling more drag-reducing laminar flow. On the left wing, Boeing evaluated technologies to reduce environmental effects on natural laminar flow as a way to improve aerodynamic efficiency. Following the flight test program, Boeing and the Aircraft Fleet Recycling Association recycled the 757 using environmental best practices.

The Airbus Group's E-Fan all-electric demonstrator aircraft.

Airbus ProSky partnered with **Flightradar24** to utilize their aircraft positional data along with other information in a new flight-tracking platform, AirFlight, to ensure aircraft operators have the tools necessary to operate efficiently, predictably, and sustainably from gate to gate.

Japanese scientists transmitted energy wirelessly, an important step that could one day make solar power generated in space and transmitted to Earth a possibility. Also, Lockheed Martin reported a technological breakthrough in developing a power source based on nuclear fusion, saying that in about a decade a small reactor could be ready.

In August, AFRL, Lockheed and NASA conducted a 4 percent-scale semi-span test in the National Transonic Facility at NASA's Langley Research Center in Virginia to validate the **hybrid wing body design**, which could burn 70 percent less fuel than legacy transport planes.

Small strakes patented by Lockheed Martin, called microvanes, were shown to reduce drag by 3.5 percent in flight testing by AFRL and Lockheed Martin. In 2015, the Royal Canadian Air Force installed microvanes on a C-130J-30 for a two-year in-service test. The U.S. Coast Guard has outfitted a C-130J with microvanes to assess fuel burn reduction and long-term operability. Microvanes are also on the production LM-100J, a derivative of a C-130J-30.

Researchers aim for hypersonic missiles and transport vehicles

by Kevin Kremeyer

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

The international hypersonics community this year conducted a wide range of research and facility upgrade work:

Europe-Russia: European and Russian officials collaborated on Mars entry studies. France's aerospace research center, ONERA, tested Russian plasma-assisted combustion for high-speed propulsion.

Europe-Japan: The European Union and Japan Aerospace Exploration Agency performed design studies for a high speed aircraft under the HIKARI project and thermal management studies on the THOR project.

Australia-Europe-U.S.: The German Aerospace Center and the Air Force Research Laboratory conducted airframe, inlet aerodynamic and aerothermal tests at Mach 8 under the Hypersonic International Flight Experimentation project, at the Arnold Engineering Development Complex in Maryland. Australia's Defence Science and Technology Organisation and AFRL continued their cooperative Hypersonic International Flight Research Experimentation, HIFiRE, program. Australian researchers collaborated with European partners on the HEXAFLY-International project toward testing a Mach 8 vehicle. University of Queensland coordinated multiple Australian Universities, DSTO and international collaborators.

China: The Chinese Academy of Sciences' Institute of Mechanics finished calibrating its 3.5-meter-diameter J-12 hypervelocity tunnel up to Mach 9, with heat transfer measurements and simulations yielding accurate results for external aerodynamics and supersonic combustion trains. After multiple Wu-14 hypersonic glide vehicle re-entry flights, China unveiled its new Mach 10-12 DF-21D missile.

Europe: The European Space Agency's Intermediate Experimental Vehicle spaceplane was boosted to an altitude of 412 kilometers in February and splashed down in the Pacific, to mimic entry from low Earth orbit. Reaction Engines of the U.K. continued work on the British government-European Space Agency-funded Skylon spaceplane, preparing for flight tests by 2020. Airbus received international patents on a Mach 4.5 military-commercial passenger, long-range vehicle. Universitaet Göttingen participated in the Cryogenic Hypersonic Advanced Tank Technologies program and implemented Magneto-Hydrodynamic flow control in its High Enthalpy Shock Tunnel. Facility upgrades included: modifications to the HELM shock-tunnel at Universitaet der Bundeswehr Muenchen to simulate Martian re-entry; scramjet testing capabilities at ONERA's F4 high enthalpy facility; installation of three tunnels at Oxford — T6 Stalker Tunnel (High total enthalpy); High Density Tunnel (High Reynolds number); and Low Density Tunnel (Rarefied).

Russia: After conducting the first launch of the heavy-lift Angara A5 vehicle in 2014, launch services are planned for global customers, including from the new Vostochniy site. Hypersonic aerodynamics and heating studies for Angara 5 were performed by TsAGI, which is currently pursuing Winged Reusable Rocket Modules. After the fourth flight test of its next generation Yu-71 Mach 10 missile, Russia's Rosoboronexport signed a contract to sell the S-400 Mach 6.2 air defense system to China.

Japan: The Japan Aerospace Exploration Agency is more than halfway through its plan to develop a hypersonic transport that would cross the Pacific Ocean in two hours by 2025. Tests of hypersonic inlet-starting and a pre-cooled turbojet engine have paved the way for its Mach 5 test of a ram jet turbo-fan engine, while design, materials, airframe and aerodynamics studies continue. Beyond JAXA's current launch vehicle development program, the hypersonic transport will yield lower-cost, on-demand space access.

U.S.: Four flight tests were completed toward a Conventional Prompt Global Strike capability. DARPA's XS-1 Reusable Experimental Spaceplane program faces a go/no-go decision in 2016. DARPA also funded Raytheon to continue work on a hypersonic tactical boost glide vehicle. AFRL plans to scale up Boeing and Aerojet-Rocketdyne's X-51 Mach 5 scramjet 10-fold, followed by 100-fold. NASA funded a Lockheed Martin-Aerojet Rocketdyne feasibility study of the propulsion concept for their SR-72 Mach 6 aircraft. DARPA identified four engines for long-range combined cycle operation and demonstrated transition from turbojet to ram jet mode without unstarting the inlet. AFRL is also developing a High Speed Strike Weapon, and together with DARPA is developing a Hypersonic Air-breathing Weapon Concept.

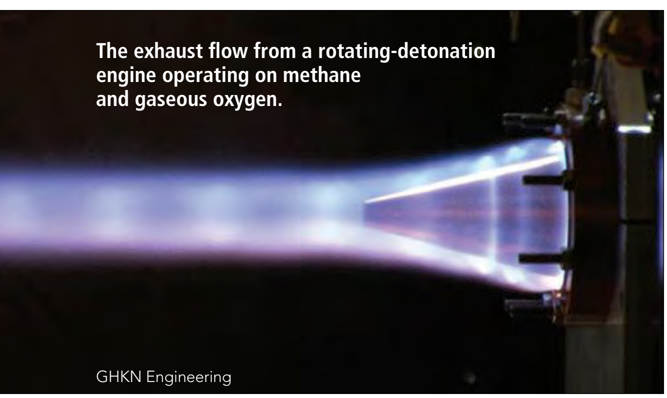
Infrastructure upgrades are being performed to enable more accurate testing: **update** the NASA Langley's 8-foot High Temperature Tunnel (HTT) to be capable of testing at Mach 3, 4, 5 and 7; **increase** the run time and stagnation pressure over which Purdue University's Ludwieg tube remains quiet; **benchmark** the CUBRC company's Large Energy National Shock tunnels against re-entry and scramjet flight data; **expand** AEDC's Hypervelocity Wind Tunnel 9 to Mach 18; and **expand** the National Aerothermochemistry Laboratory for larger-scale tests of PM&AM Research's energy deposition technologies for revolutionary external-internal high-speed flow-control.

Artist rendering of the SR-72 hypersonic aircraft. NASA is funding a study of the Mach 6 plane.

Global interest grows in pressure gain combustion

by Kazhikathra Kailasanath

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.*



The exhaust flow from a rotating-detonation engine operating on methane and gaseous oxygen.

GHKN Engineering

Interest continues to grow worldwide in pressure gain combustion, a propulsion process in which the total pressure of the exit flow exceeds that of the inlet flow on an appropriately averaged basis.

In the U.S., the Air Force Office of Scientific Research, Office of Naval Research, **DARPA** and the Department of Energy continue to support research projects at locations across the country. Work continues with academic institutions as well, including the Naval Post Graduate School, the University of Texas at Arlington, University of Cincinnati, University of Connecticut and Purdue University. Internationally, China, France, Japan, Poland, Russia, Singapore and Taiwan maintain very active research and development programs in PGC.

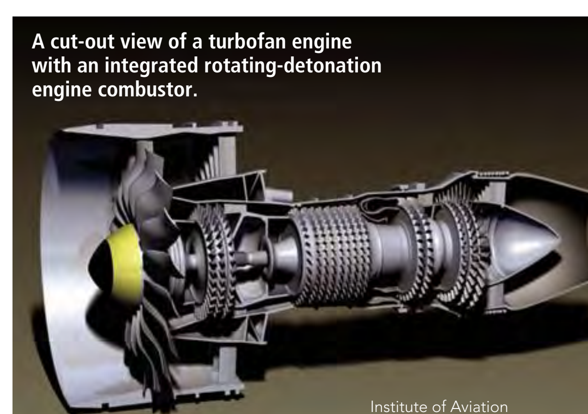
Overall, the global emphasis has shifted from pulsed-detonation engines to continuous or rotating-detonation engines. At the same time, alternates to detonation engines, such as wave-rotors and pulse combustors, continue to receive attention.

A team comprising HyPerComp, University of Connecticut, Naval Postgraduate School and Aerojet Rocketdyne is conducting analysis and experiments to demonstrate a single turbine stage integrated into a **continuous detonation engine** (CDE). The goal is to understand the role of the unsteady processes of the CDE driving the turbine and to explore avenues for performance enhancement.

United Technologies Research Center is continuing to develop PGC technology, funded in part with two major government contracts. One is the Department of Energy's "Combined Cycle Power Generation Employing Pressure Gain Combustion" study to assess if PGC technology can achieve 65 percent thermal efficiency for a gas turbine combined-cycle power generation application. The other is the DARPA-funded "**Rotating Detonation Engines Combined Cycle**" study, focusing on designing high performance rotating-detonation engines for a direct-thrust application.

GHKN Engineering of Redmond, Washington, completed a series of tests to evaluate the suitability of continuous detonation rocket engines (CDRE) for space applications. The test program measured performance over a wide range of stable operating conditions (equivalence ratio, feed pressure, flow rate) for ethylene/gaseous oxygen, methane/GOX, and ethane/GOX. Specific impulse, or Isp, values as high as 192 pound-force-second/pound-mass were recorded with methane/GOX. Tests that evaluated resistance to acoustic interference and direct detonation upset demonstrated combustion stability as one of the key attributes of CDREs for space application, especially with "**green**" **propellants** such as methane/GOX. Extended pulse-mode firings with methane/GOX demonstrated the potential for CDREs as attitude control thrusters.

Notable developments outside the U.S. include experimental observation from a Japanese research group of Nagoya University, Keio University and the Japan Aerospace Exploration Agency. The group found that the efficiency of rotating-detonation-rocket combustor characteristic velocity is more than 95 percent using precise mass flow and thrust measurements. In France and Poland, work continued on several advanced efforts in the development and testing of rotating-detonation engines, including research on a turbofan engine with RDE by the Institute of Aviation in Warsaw. In China, Peking University continues to experiment with a **cylindrical chamber RDE** (instead of the typical annual chamber adopted by most researchers). Chinese researchers are among those around the world who have made significant progress in the numerical simulations of representative configurations with various degrees of fidelity for all the complex physical and chemical processes involved. There is also significant interest in developing appropriate exhaust system configurations for these dynamic systems that minimize unwanted pressure oscillations and maximize performance, including the Mach number distribution from a typical three-dimensional numerical simulation of an RDE with a converging-diverging nozzle.



A cut-out view of a turbofan engine with an integrated rotating-detonation engine combustor.

Institute of Aviation

Artist's concept of the spaceplane being designed for DARPA by Northrop Grumman, with help from its Scaled Composites company and Virgin Galactic.

Northrop Grumman

SpaceX reaffirms commitment to reusability

by Adam Dissel and Barry Hellman

*The **Reusable Launch Vehicles Program Committee** brings together experts to focus on leading-edge programs and developments in this area.*

Interest in reusable launch systems and spacecraft continues to sustain multiple commercial and governmental development efforts, many of which are scheduled to achieve significant milestones in the coming year.

DARPA has been actively working the **Experimental Spaceplane** (XS-1) program with the main objective to mature aircraft-like operations for a launch vehicle with a reusable first stage. There are three prime contractors working the program: Boeing, Masten Space Systems and Northrop Grumman. The program has completed a year-long preliminary design phase, and DARPA has decided to continue to mature the designs for another year before moving into the critical design, build and fly phases.

The launch vehicles are designed to put at least 3,000 pounds of payload into low-Earth orbit and support hypersonic testing. The program's flight testing will include flying the first stage 10 times over 10 consecutive days, launching at least a 900-pound payload into LEO.

Reaction Engines of Oxfordshire, U.K., continues to make progress on developing the pre-cooling heat exchanger and other components of the Synergetic Air Breathing Rocket Engine (SABRE). This engine has the potential to enable a horizontal takeoff hypersonic access to space launch system. Reaction Engines has been collaborating with the U.S. Air Force Research Laboratory and the U.K. Defence Science and Technology Laboratory to explore applications of the pre-cooler heat exchanger. SABRE was expected to be awarded 60 million pounds ($92 million) from the British government to move to the next phase of development. In October, Reaction Engines announced a 20 million pound ($30 million) investment from BAE Systems.

SpaceX has reaffirmed its commitment to reusability as an essential element of the company's vision for the future of spacelift. Following several attempts to recover its Falcon 9 first stage, SpaceX officials expect a successful recovery within the next year on the company's downrange drone ship. The Falcon Heavy configuration is planned to fly in 2016 and will eventually feature the ability to recover and reuse all three first stage cores.

Swiss Space Systems continues to make progress on the **Soar three-stage launch system**. Activities completed include wind tunnel testing in Europe, improved aerodynamics through coupled analysis and test, thermal protection optimization and analog software simulations on replica hardware. Soar development is expected to progress toward major program milestones in the coming year.

XCOR, based in Mojave, California, continues to make progress on its **Lynx suborbital spaceplane** and has completed a significant portion of the vehicle build. The Lynx Mark 1 is scheduled to begin flight testing in 2016.

Generation Orbit of Atlanta is proceeding with the development of the GO Launcher 1 suborbital vehicle that is air launched from a business-jet-class aircraft. The company has completed several captive flight tests with representative hardware and is planning to reach system preliminary design review in 2016. The **GO Launcher 1** is intended as a flight test platform and is capable of achieving a wide variety of test conditions.

Virgin Galactic concluded the investigation of the October 2014 flight test accident of the suborbital SpaceShipTwo and implemented changes to correct the premature activation of the vehicle's wing feather system. Construction on the next SpaceShipTwo airframe is advancing rapidly. Additionally, Virgin Galactic is continuing development of the LauncherOne small spacelift system.

In February, the European Space Agency flew the Intermediate eXperimental Vehicle. The IXV features a lifting-body design and a ceramic matrix composite thermal protection system. Launched by the Vega rocket into LEO, the IXV successfully demonstrated atmospheric entry from orbital velocity and descended under chutes to an ocean splashdown. The configuration and material technologies demonstrated are relevant to future reusable systems and ESA plans future IXV flights that will be recovered on land.

Next-gen weather satellites complete thermal vacuum testing

by Brian O'Connor

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

GOES-R, the first of four planned next-generation Geostationary Operational Environmental Satellites, completed thermal vacuum testing this year at Lockheed Martin Space Systems near Denver. Supporting teams from NASA, NOAA, and five instrument facilities completed the two-month test in which the satellite was exposed to the harsh vacuum and temperature environment of space.

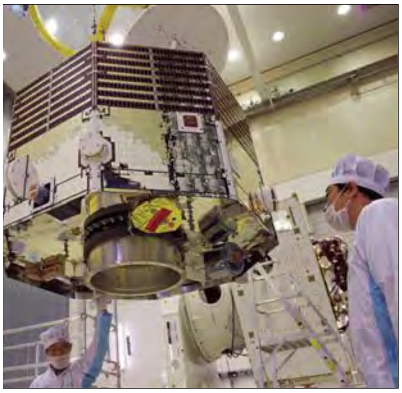
The Geostationary Operational Environmental Satellite-R being prepared for transport from the clean room to the vacuum chamber for environmental testing.

Lockheed Martin

The primary goal was to perform repeated system-level testing at extreme temperatures and to demonstrate thermal subsystem performance, including the spacecraft's more than 100 heat pipes, multilayer insulation, coatings and heater circuits. Post-test thermal model correlation is underway and was expected to be completed before the end of the year. Launch is scheduled for October from Kennedy Space Center.

NASA's Space Launch System completed its critical design review this year. The SLS will be the most powerful rocket ever built and will enable astronauts in the Orion spacecraft to travel deeper into the solar system. The review provided an evaluation of the thermal design and analysis, including thermal environments, integration and interfaces models verification and validation plans. This included assessments of the thermal environments on shared compartments environments across the vehicles due to **aerodynamic and engine plume heating**. The review led to design changes to reduce risks and improve plans for models verification and validation.

Japan's Mercury Magnetospheric Orbiter is unboxed in April at the European Space Research and Technology Centre near Amsterdam.



European Space Agency

With pre-phase A and risk reduction activities completed for the **Wide Field InfraRed Survey Telescope** using Astrophysics Focused Telescope Assets (WFIRST-AFTA), the mission concept review was scheduled to take place before the end of the year. The spacecraft will use a repurposed telescope from the National Reconnaissance Office. The spacecraft will be a serviceable observatory for imaging the near infrared sky, measuring dark energy, and searching for exoplanets. WFIRST-AFTA is planned as a joint mission between NASA's Goddard Space Flight Center in Maryland and the Jet Propulsion Laboratory. Precise roles and responsibilities are still being determined, but GSFC will manage the mission and integration and testing of the spacecraft. JPL will provide the coronagraph instrument. Industry studies are currently underway to determine which organizations will provide the spacecraft bus and Wide Field Instrument. While the thermal designs for the existing telescope and the coronagraph instrument are passive, the initial design of the Wide Field Instrument will incorporate a reverse Brayton cycle cryocooler with a neon fluid loop to actively cool the two channels of the instrument to below 100 kelvins (-173° Celsius).

The **Mercury Magnetospheric Orbiter**, built by the Japan Aerospace Exploration Agency (JAXA) for the BepiColombo mission, passed its thermal-vacuum test and was shipped to the mission partner, the European Space Agency (ESA). Each agency has developed separate orbiters that will be launched together. ESA's orbiter is called the Mercury Planetary Orbiter. JAXA's orbiter required new thermal control technologies for the high temperature environment that it will be exposed to in orbit around Mercury. This includes a high temperature insulation that consists of layers of titanium foil separated by layers of ceramic fibers. Additionally, a high temperature resistant and high thermal conductive honeycomb panel was also developed for the solar array installed side panels.

Another thermal-vacuum test done by JAXA was for its **Astro-H mission**. The telescope will conduct X-ray astronomy and includes instruments developed by NASA and the Canadian Space Agency. The chamber that the spacecraft was tested inside was 13 meters in diameter and four-stories tall. The telescope and its instruments employ advanced thermal control technologies, including many heat pipes for transporting heat around, two 4.5 kelvins (-268° Celsius) Joule-Thomson coolers, and a two-stage adiabatic demagnetization refrigerator that can go down to 50 millikelvin.

Solar-system exploration marks banner year

by Chris Moore

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

This was a banner year for solar-system exploration with missions to two dwarf planets and a comet.

After traveling for 10 years and three billion miles, the New Horizons spacecraft's historic **flyby of Pluto** on July 14 completed an initial survey of all planets in the solar system. New Horizons captured spectacular images of mountain ranges and frozen plains on Pluto's surface, and of its five known moons.

After leaving the asteroid Vesta in 2012, the Dawn mission entered orbit around the dwarf planet Ceres and discovered several bright spots of unknown origin. In August, the European Space Agency's Rosetta mission watched **Comet 67P/Churyumov–Gerasimenko** release streamers of gas as it warmed during its approach to perihelion. Intermittent contact was reestablished with the wayward Philae lander.

The Kepler spacecraft discovered its 1,000th confirmed extrasolar planet, including a planet 60 percent larger than Earth that orbits within the habitable zone of a Sun-like star. This planet, called Kepler-452b, is 1.5 billion years older than Earth.

In human space exploration, American astronaut **Scott Kelly** and Russian cosmonaut **Mikhail Kornienko** were launched to the International Space Station in March to begin a one-year mission to investigate 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 more than 1,000 days.

Development on NASA's Space Launch System continued its progress. Several tests of the RS-25 engine that will power the SLS were conducted at Stennis Space Center. A five-segment solid rocket booster was also tested in Utah. The critical design reviews for both SLS and Orion were completed in October.

SpaceX conducted a successful pad abort test of their Dragon capsule for NASA's Commercial Crew Program. In June, a SpaceX Falcon 9 rocket failed during launch on a mission to resupply the ISS. **Blue Origins** launched its New Shepard rocket on its first suborbital flight test, reaching an altitude of over 300,000 feet.

NASA decided to pursue a mission concept for its Asteroid Redirect Mission that will use a robotic spacecraft to capture a boulder from the surface of a near-Earth asteroid and place the boulder into a stable lunar orbit for exploration by astronauts. ARM will also test techniques for deflecting the asteroid to demonstrate planetary defense capabilities. Work is progressing on development of the solar electric propulsion system, rendezvous sensors, and autonomous robotic manipulators for the mission.

In space exploration technology, **Bigelow Aerospace** delivered an inflatable module for launch to ISS. Deployment and structural integrity of the module will be demonstrated during its two-year mission on ISS to aid in the design of future deep space habitats. NASA conducted a second test of a low-density supersonic decelerator for landing heavier payloads on Mars. The test vehicle was dropped from a high altitude balloon, but the supersonic parachute failed during deployment. NASA also completed human-in-the-loop testing of a portable life support system for an advanced space suit.

Pluto, as seen through blue, red, and infrared images taken on July 14 by Ralph, a multispectral imaging camera aboard NASA's New Horizons spacecraft.

Electric power shines in New Horizons, Messenger missions

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.*

Significant 2015 milestones in aerospace power systems included the New Horizons spacecraft's flight through the Pluto system in July. That journey came after a very long cruise that began with the probe's launch in 2006. The spacecraft was powered by a general-purpose heat source **radioisotope thermoelectric generator** producing about 200 watts at the time of the encounter with Pluto. New Horizons is performing well and sending data to Earth while on its way to the next target in the Kuiper Belt. The Johns Hopkins University Applied Science Physics Laboratory designed, built, and operates the spacecraft for NASA.

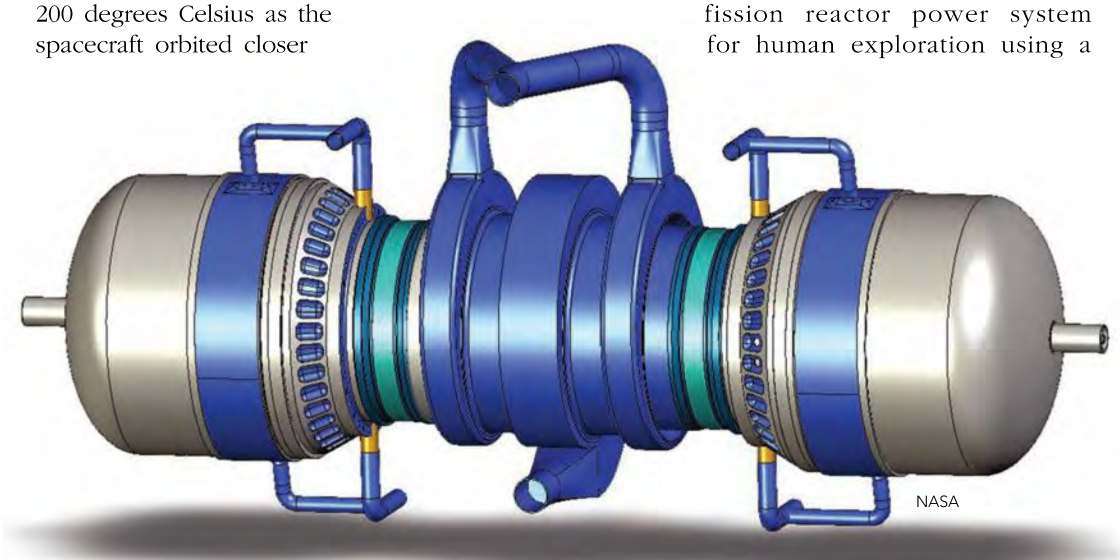
NASA's Messenger mission came to an end when the APL-built spacecraft impacted the planet Mercury on April 30 as planned. Messenger was launched in August 2004 and went into orbit around Mercury in March 2011. The spacecraft was powered by a high-temperature solar array that survived the extreme temperature and radiation environment. The temperatures on the array reached a maximum above 200 degrees Celsius as the spacecraft orbited closer to the surface of the planet.

NASA released the **Nuclear Power Assessment Study** in June, a report on a sustainable strategy for safe, reliable, and affordable nuclear power systems for space exploration. After examining the agency's goals for the next 20 years, NASA concluded that there will be a need for radioisotope power systems and their development well into the 2030s. The study also considered the extensibility of the technology to human exploration and operation mission goals.

NASA this year discontinued work on the **Advanced Stirling Radioisotope Generator**, ASRG, for flight application because of budget constraints. NASA continues to recognize the need for high-efficiency Stirling power conversion for radioisotope power systems and continues investment in the technology including production of the Advanced Stirling Convertor ASC-E3 design by Sunpower Inc. of Athens, Ohio.

The ASRG configuration featured a pair of ASC convertors mounted dual-opposed. In total, NASA Glenn Research Center has tested over 40 Stirling convertors under the Radioisotope Power Systems Program, accumulating over 760,000 hours of operation. The Stirling generator would use only one-quarter of the **plutonium dioxide fuel** needed by comparable radioisotope thermoelectric generators to produce a similar amount of power, thus extending the limited national supply of plutonium-238.

Work continued on a non-nuclear technology demonstration of a large fission reactor power system for human exploration using a 12-kilowatts-electric Stirling Power Conversion Unit under development by Sunpower. The Power Conversion Unit features a unique **sodium-potassium heat exchanger** that allows it to be integrated with an electrically heated reactor simulator developed by NASA Marshall Space Flight Center in Alabama that includes a pumped sodium-potassium heat transfer loop. The power conversion unit is comprised of two, 6-kilowatts-electric free-piston Stirling engines. The unit was delivered in August 2015 and testing was completed.



NASA and Sunpower are developing a 12-kilowatts-electric power conversion unit for use in the non-nuclear technology demonstration of a fission reactor power system.

Another busy year for electric propulsion

by John Dankanich

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

It's been a year of diverse research, innovation and operations in the field of electric propulsion.

Japan's **Hayabusa-2** asteroid explorer, propelled by four microwave discharge ion engines, completed its first maneuver in March, setting the stage for the spacecraft to collect a sample from asteroid 1999JU3 and return it to Earth. Also, NASA's Dawn spacecraft achieved orbit around the dwarf planet Ceres. Dawn's Ion Propulsion System has operated for over 47,000 hours and used 395 kilograms of xenon to deliver approximately 11 kilometers/second of Delta-V, or change in velocity, to the spacecraft.

NASA's Space Technology 7 demonstration is scheduled for launch in December on the European Space Agency's **LISA Pathfinder** Spacecraft to test eight colloid thrusters made by Busek Space and Propulsion Systems of Massachusetts. Also, the Air Force Research Laboratory, the service's Space and Missile Systems Center and its Rapid Capabilities Office collaborated to host a Hall thruster experiment this year aboard the X-37B to characterize performance improvements relative to previous units on board the Advanced Extremely High Frequency spacecraft.

In the area of small-spacecraft propulsion, a **micro-cathode arc thruster** developed by George Washington University was launched in May. The thruster reduced the initial tumble rates from 30 degrees/second to 1.5 degrees/second within 48 hours of deployment. Also, the Missouri University of Science and Technology is developing a multi-mode system that integrates electrospray with catalytic microtube propulsion.

Iodine technology continues to gain momentum as the iodine Satellite (iSat) project heads toward critical design review at NASA's Marshall Space Flight Center in Alabama. The spacecraft will demonstrate the BHT-200-I Hall thruster. Also, Busek's BIT-3 RF ion thruster was selected for flight on the Lunar IceCube mission.

The **PPS 5000 Hall effect thruster** from Snecma will be delivered for flight on the Airbus Eurostar E3000 Electric Orbit Raising (EOR) satellite in 2016 and is scheduled for flight on Eutelsat's E172B in 2017. Space Systems Loral awarded flight sets of PPS 1350-E Hall thrusters, with 2.5 kilowatt discharge power.

Aerojet Rocketdyne in June announced an agreement to supply its 5 kilowatt XR-5 Hall thruster subsystems for Lockheed Martin's modernized A2100. A few months earlier, in February, Aerojet Rocketdyne announced agreement to supply XR-5s to Orbital ATK for its all-electric GEOStar 3 satellites. European Space Propulsion is to qualify the XR-5E European variant.

NASA's Glenn Research Center in Ohio and the Jet Propulsion Laboratory in California continue to develop the 12.5 kilowatt Hall Effect Rocket with magnetic shielding propulsion system. Testing verified magnetic shielding over 2000-3000 seconds specific impulse. Integrated thruster Power Processing Unit testing operated at 12.5 kilowatts and up to up to 800 volts.

NASA awarded a cost-share contract to build two NASA **Evolutionary Xenon Thruster** systems and power processing units as part of a commercial transition project. The hardware has been offered as government furnished equipment for the latest Discovery Mission opportunity.

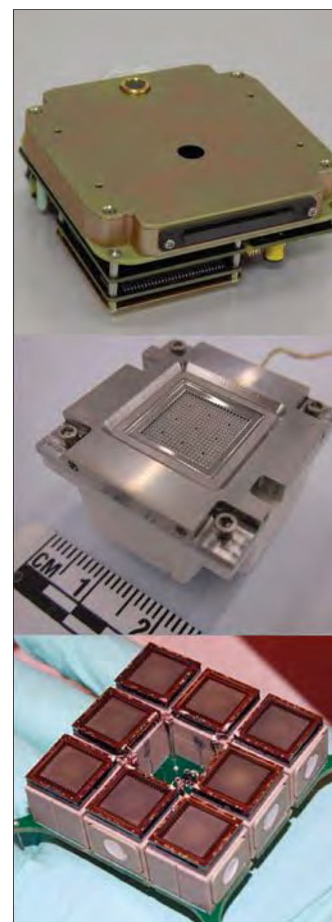
NASA Glenn, the Aerospace Corp. and the University of Michigan continued maturation of the annular ion engine for high thrust-to-power operation over a broad power and specific impulse range. Tests of the 65 centimeter thruster demonstrated uniform plasma and broad throttling range with flat carbon grids.

The **University of Stuttgart** demonstrated a spherical inertial electrostatic confinement system with anode outlet triggering a jet of both electrons and ions with high kinetic energy with potential high impulse low-power thruster.

At the component level, New Jersey-based Marotta continues to characterize its multi-function valve and completed testing with the Sitael (Alta) 5 kilowatt Hall effect thruster. Also, VACCO Industries of California and Alabama delivered custom iodine proportional flow control valves for iSat and completed the qualification of proportional flow control module options.

Electrospray work included three Game Changing Development awards to mature 100 micronewton systems to technology readiness level 5 with MIT, JPL and Busek Co. Busek also delivered electronics for its BET-1 (1 millinewton) 100 watt electrospray thruster system.

At high power, NASA **NextSTEP propulsion grants** were awarded to a team from Aerojet Rocketdyne, University of Michigan and JPL to demonstrate a 100 kilowatt Hall system; to Ad Astra Rocket of Texas for high power, long duration testing of its variable specific impulse magnetoplasma rocket; and to MSNW of Washington for its electrodeless Lorentz force thruster.



Busek/NASA/MIT

Miniaturized electrospray thrusters from, top, Busek Space Propulsion and Systems, Jet Propulsion Laboratory (3-centimeters-wide thruster) and the Massachusetts Institute of Technology.

Adaptive-cycle engine design continues to mature

by Michael G. List

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

Development and testing of advanced engine technologies is a staple in the gas turbine industry. In the forefront were collaborative efforts for advanced materials, improved production and maintenance capabilities, affordability and development of new research facilities.

GE and the U.S. Air Force Research Laboratory tested the **world's first three-stream, adaptive-cycle engine** under the Adaptive Versatile Engine Technology, or ADVENT, program. ADVENT recorded the highest combined turbine and compressor temperatures to date. The engine also featured the industry's most expansive use of ceramic matrix composites, or CMCs, in the hot section. GE continues to mature its adaptive cycle design with the Air Force through the Adaptive Engine Technology Development program. Through the program, GE tested the world's first rotating CMC blades in the low-pressure turbine. In addition, GE Aviation will spend $500 million in 2015 on technology maturation testing for the new **GE9X engine** for the Boeing 777X. Tests include the CMC demonstration testing, high-pressure compressor testing and the first demonstration core test.

The Trent XWB powered the first service flight of the Airbus A350 XWB in January.

GE and the U.S. Army continue to make progress with the Future Affordable Turbine Engine, with rig testing this year and engine testing scheduled for early 2016.

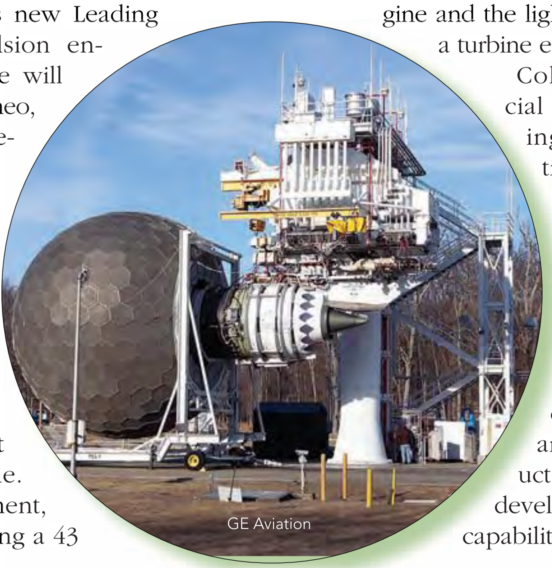
On the commercial front, testing continues on CFM International's new Leading Edge Aviation Propulsion engine. The LEAP engine will power the Airbus A320neo, COMAC C919 and Boeing 737 MAX aircraft.

Rolls-Royce joined Airbus and Qatar Airways to mark the first **Airbus A350 XWB** to enter service in January, powered by Trent XWB engines, the world's most efficient large civil aero engine. To continue development, Rolls-Royce is supporting a 43 million-euro research program to test turbine technologies that will go into its future engine design, **UltraFan**. UltraFan will offer at least 25 percent improvement in fuel burn and emissions compared with first generation Rolls-Royce Trent engines. Rolls-Royce also participates in Clean Sky 2, a public/private Joint Technology Initiative that brings together Europe's industrial aeronautics leaders, public research organizations and subject matter experts to develop and demonstrate breakthrough technologies for the civil aerospace market, reducing emissions and noise and securing the continued competitiveness of the European aviation industry. In March, Rolls-Royce also opened an advanced repair facility for components of the **LiftSystem for the F-35 Lightning 2 aircraft**. The LiftSystem, which provides the vertical-lift capability for the F-35B, is comprised of a LiftFan, 3-Bearing Swivel Module, a roll post under each wing, and a shaft connected to the aircraft's Pratt & Whitney F135 engine.

The University of Notre Dame and several public and private partners have been developing a **Turbomachinery Facility** in Ignition Park in South Bend, Indiana. The facility will include numerous test cells for full-scale, engine-condition compressor and turbine rigs as well as substantial computing capabilities. The experimental and computing resources will spur collaboration with industrial, government, and academic partners in the aircraft, power, and oil and gas industries.

The $2 million **Air Force Prize** kicked off in May, a first-ever attempt by the service to use a prize award to spur development of a new type of turbine engine. The winner, the first engine to pass all testing requirements, is meant to combine the fuel efficiency of a piston engine and the lightness and durability of a turbine engine.

Collaboration on crucial technologies impacting materials, production and maintenance, and affordability has yielded impressive results for the gas turbine engine community. Current and future products have been based upon decades of development, and the trend of product improvement through development of new testing capabilities continues.



GE Aviation's GEnx engine (center) is tested as part of development for the GE9X engine, which will be the company's most fuel-efficient engine.

Busy year of scramjet research

by Dora E. Musielak and Bayindir H. Saracoglu

*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.*

After flying its **X-51A WaveRider demonstrator** to a top speed of Mach 5.1 in 2013, the Air Force Research Laboratory conceived a promising program to advance supersonic-combustion ramjet propulsion even further. This High Speed Strike Weapon, or HSSW, program will demonstrate hypersonic missile technologies for striking heavily defended targets from standoff ranges.

Meanwhile, DARPA's **Hypersonic Airbreathing Weapon Concept**, or HAWC, program will pursue flight demonstration of the critical technologies for effective and affordable air-launched hypersonic cruise missiles, including hydrocarbon scramjet-powered propulsion to enable sustained hypersonic cruise.

The Hypersonic Airbreathing Propulsion Branch at NASA's Langley Research Center in Virginia continues to support AFRL's medium-scale critical components, HSSW, the large-scale Scramjet engine test technique and DARPA's HAWC programs.

Langley's Arc-Heated Scramjet Test Facility is "undergoing final upgrades to increase its test capability," says NASA's Richard Gaffney, head of the Hypersonic Airbreathing Propulsion Branch. The **Direct-Connect Supersonic-Combustion Test Facility** was brought back online in June after being dormant for several years. Another effort is underway at Langley to design and construct a new water-cooled Mach-6 nozzle for the 8-Foot High Temperature Tunnel.

In April, NASA Glenn Research Center and AFRL began phase-three testing of the Combined Cycle Engine-Large Scale Inlet Mode Transition Experiment C in the 10-by-10-foot Supersonic Wind Tunnel. The combined-cycle engine, CCE, project aims to demonstrate closed-loop control to enable smooth and stable inlet operation throughout mode transition without unstart for turbine-based combined cycle propulsion.

"NASA has demonstrated mode transition of the CCE inlets at Mach 3+," says Paul Bartolotta, deputy manager of the Hypersonics Project at NASA Glenn. "The next step is to put live propulsion into the CCE inlet hardware and test mode transition."

The High Speed Strike Weapon demonstrator will test technologies for a standoff missile.

To define CCE test parameters, Glenn is investigating the feasibility of utilizing a commercial off-the-shelf turbine for a flight demonstration vehicle. This should reduce the cost of the demonstration program.

In August, a scramjet was launched from the Andøya Rocket Range in Norway on the seventh mission under the joint Australia-U.S. Hypersonic International Flight Research Experimentation, or **HIFiRE**, program. "The scramjet commenced during reentry after completing a suborbital flight, while the payload accelerated to over Mach 7," says Michael Smart, the science lead at the University of Queensland for the HIFiRE 7 flight. "The acquired data showed that the vehicle was functioning perfectly, flying on the correct trajectory, and supersonic airflow was established in the combustor." The HIFiRE program is intended to determine scramjet start at high altitudes and to measure engine thrust at lower altitudes.

Phase 3 tests began in April in the 10′×10′ Supersonic Wind Tunnel for the NASA/Air Force Research Laboratory's combined-cycle engine — large scale inlet for mode transition experiment.

The **International Space Plane Hypersonic Systems and Technologies Conference** was held in Scotland in July. Adam Siebenhaar, a retired Aerojet executive and conference chairman, says: "The unexpected high conference attendance refreshingly reflects a revived global interest and investment in hypersonic technologies."

Development of the **Sabre4 engine** that will propel the single-stage-to-orbit Skylon D1 continues after a successful precooler and frost control demonstration in 2012. "Development includes technology programs addressing intake and nozzle aerodynamics, durable combustion chambers, and lightweight heat exchangers," says Richard Varvill, technical director at Reaction Engines in Oxfordshire, U.K.

In Japan, Aoyama Gakuin University simulated a rotating detonation engine fueled with gaseous JP10-air. Researchers obtained mixture-based specific impulse data by using a two-step reaction mechanism.

Russia's Central Institute of Aviation Motors developed a scramjet module for the European Space Agency's **High-Speed Experimental Fly Vehicles International demonstrator**. The program aims to advance high-speed civil aircraft. Comprised of fixed-geometry inlet, elliptical expanding combustor, two-stage fuel injection system with flame stabilizers and axisymmetric nozzle, the scramjet was successfully tested at conditions simulating Mach 7.4 flight.

Expanding the global footprint of hybrid rocketry

by Joseph Majdalani

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

The field of hybrid propulsion marked 2015 with several notable accomplishments, global collaborations and geographical expansions.

After six years of development, a group of German students from Technische Universität München brought hybrid rocketry to Brazil in May by launching a self-pressurizing 225 pound-force **WARR-EX 2 motor** to an altitude of 4.3 kilometers off the country's Natal coast. WARR, the German Scientific Workgroup for Rocketry and Space Flight, has been actively promoting hybrid propulsion across Europe.

Also in May, SystemsGo, the nonprofit STEM education program based in Fredericksburg, Texas, that specializes in promoting hybrid rocketry in high schools, finished testing nearly 100 Tsiolkovsky and Oberth rockets from sites in Texas. These vehicles aim to either lift one pound of payload one mile high, or break the sound barrier. **SystemsGo** so far has trained 85 new teachers to implement its sequenced, four-year aeroscience curriculum. The group has also launched all six Goddard-level vehicles, targeting an altitude of nearly 30 kilometers, from the White Sands Missile Range in New Mexico.

In July, Texas students traveled to White Sands Missile Range in New Mexico to test their rockets. Left: A rocker from Houston's Booker T. Washington High School; right: San Antonio's Alamo High School.

Researchers at JAXA, the Japan Aerospace Exploration Agency, simulated a hybrid design that utilizes an altering-intensity, swirl-oxidizer type flow. This design enhances performance through continuous, thrust-independent control of the oxidizer-fuel ratio. The concept featured both axial and tangential oxidizer injectors that permitted adjusting the oxidizer swirl intensity independently of the throttle setting. The demonstration indicated that the performance of such rockets could be improved by optimizing the oxidizer-fuel ratio over the course of the burn. The majority of this improvement manifested itself in the form of increased combustion efficiency and reduced unburned fuel slivers relative to a conventional swirl-oxidizer-flow-type rocket.

The Aerospace Systems Research Group at the University of KwaZulu-Natal in South Africa has developed a successor to the Phoenix-1A hybrid rocket, which was launched from the Denel Overberg Test Range in South Africa late in 2014. Phoenix-1B will employ the same ground support equipment deployed for the 1A launch, including the mobile launch platform. As the workhorse vehicle for the **South African Hybrid Sounding Rocket Program**, 1B features a revised silica phenolic/graphite nozzle. When Phoenix-1A was flown near the Western Cape, its nozzle failed, leading to off-design performance. Nonetheless, the vehicle still attained an apogee of 2,500 meters and a maximum speed of 250 meters per second during its 55-second flight. The first Phoenix-1B launch is planned for next July.

The Advanced Propulsion Research Group at Auburn University developed a working model of the **quadrupole vortex hybrid rocket engine**. The QpV motion leverages an innovative rotary concept that is capable of driving high regression rates in cylindrically-shaped grain configurations. Auburn's work builds upon previous research into the effectiveness of quadrupole vortex configurations in heat transfer applications and draws inspiration from its use as an efficient mechanical drill in the petroleum industry. The combination of these characteristics gives rise to regression rate improvements on par with other swirl-driven hybrids while at the same time offering the additional benefits of greatly increased mixing, heat transfer and combustion stability.

Commercial space drives advances in liquid propulsion

by David Ransom

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

Commercial space continued to be the dominant focus of liquid propulsion developments in 2015. In June, SpaceX completed a critical design review for an upgraded Merlin engine for later Falcon 9 flights. Orbital ATK continues with efforts to return the Antares rocket to flight following the October 2014 mishap with the CRS-3 resupply mission. Orbital is upgrading the Antares with new **RD-181 first-stage engines** for greater payload and better reliability. Certification tests were completed with seven hot fire tests and a return to flight is anticipated in 2016.

Other boost-propulsion developments this year include the completion of preliminary design review of Blue Origin's 2,447-kN (kilonewton) **BE-4 engine** with ongoing testing of its main injector, preburner, turbopump and valves. In September, ULA announced development plans for its Vulcan launch system to be powered by the BE-4 as main propulsion. ULA is maintaining the Aerojet Rocketdyne AR-1 engine as a backup option. Aerojet also completed a 535-second verification test of the RS-25 engine that will power NASA's Space Launch System (SLS), taking astronauts deeper into space.

Meanwhile, the **Stennis Space Center B-2 test stand** continues to be upgraded to support SLS stage testing. Blue Origin's BE-3 489-kN thrust engine performed flawlessly while powering the maiden flight of the company's New Shepard space vehicle on April 29.

International highlights include the Japan Aerospace Exploration Agency's (JAXA) development of the **H-3 launch vehicle**, which will be propelled by new LE-9 engines, and the European Space Agency's decision to develop a new launch vehicle, the Ariane 6. The Ariane 6 main stage will be based on a streamlined Ariane 5 design. The upper stage will be new and include the re-ignitable Vinci rocket engine. The new vehicle is being developed by Airbus Safran Launchers, a joint venture encompassing the launcher activities of Airbus Defence and Space and the propulsion activities of Safran.

The return of crew transportation capability to the U.S. is looming closer. SpaceX completed a pad abort test this May and NASA, ULA and Aerojet Rocketdyne completed Exploration Flight Test-1 (EFT-1) in December 2014. The pad-abort test was conducted using the **SuperDraco propulsion system** onboard the Dragon spacecraft. Each SuperDraco is powered by nitrogen tetroxide and monomethylhydrazine and produces 71 kN of thrust. EFT-1 was performed using the ULA Delta 4 Heavy vehicle powered by Aerojet RS-68A engines for the boost stage (3,123 kN thrust each) and one RL10B-2 engine for the upper stage producing 110 kN of thrust.

In April, a liquid-hydrogen fueled BE-3 engine lifted Blue Origin's New Shepard vehicle through Mach 3 and an altitude of 307,000 feet during its first developmental flight.

Blue Origin

Orbital Technologies, Aerojet, ULA and XCOR Aerospace report making progress in upper stage propulsion development. Orbital scaled the vortex thrust chamber assembly to the 133 kN thrust level and demonstrated that the chamber can be readily transitioned between various hydrocarbons with only minor changes to the injector elements. In December 2014, the first **AR RL10C-1 engine** flew aboard the Atlas V. The RL10C-1 delivers 102 kN of thrust for the Atlas second stage using LO2/LH2, offering reduced life cycle costs for the future. ULA also continues to work with XCOR on a novel, low cost 111 kN class LO2/LH2 engine, initiating hot fire testing of a 10 percent thrust technology demonstrator version of the engine. Airbus Safran Launchers is preparing a reusable liquid oxygen/liquid methane thrust chamber demonstrator in the 400-kN class for hot firing at DLR/Lampoldshausen. JAXA has researched the use of electron beam melting for the manufacture of cold gas thrusters that could be used for attitude control during reentry. Performance tests are in progress with qualification tests in the near future.

The Aerojet Rocketdyne-designed RS-25 engine for the Space Launch System underwent a 535-second test in August.

NASA

Initial steps for nuclear thermal rocket design

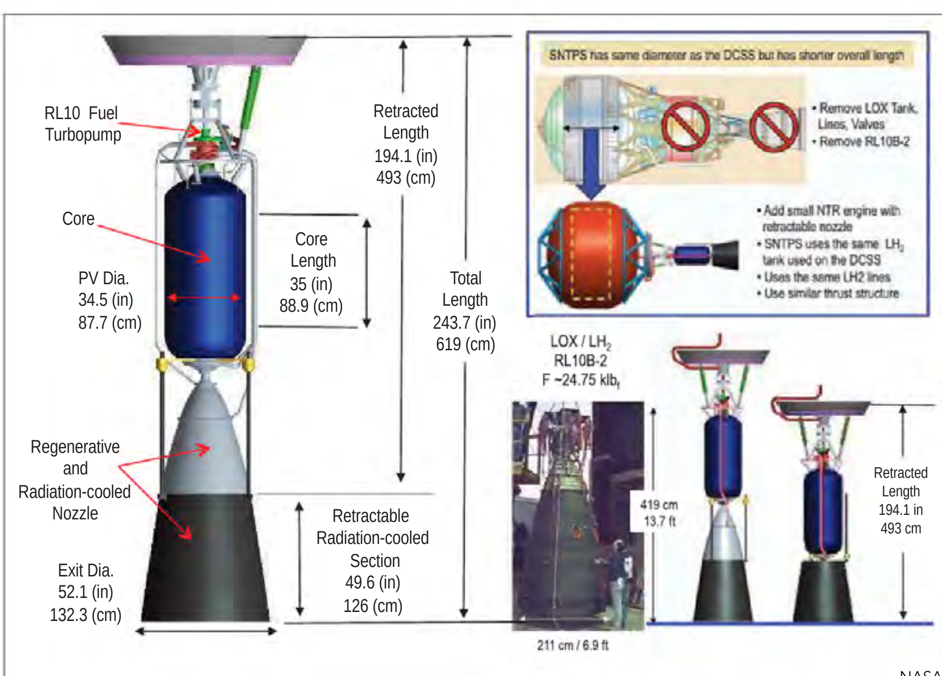
by Bryan Palaszewski

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

In 2015, the research in nuclear and future flight propulsion investigated nuclear propulsion in many forms and configurations. These nuclear propulsion systems are best suited for interplanetary travel. While there is always hope for breakthroughs, no practical ideas for fast interstellar flights within a human lifetime are showing promise. Studies point to nuclear fusion as one important option, but the power levels needed for such propulsion systems are far beyond our grasp with our current investments.

A team from the University of Connecticut, NASA Marshall Space Flight Center and the University of Michigan assessed **laser-heated pellet pulse propulsion**, LHPPP, which has the potential to compete with near-term deep space propulsion systems. LHPPP's ultimate potential, however, is in pulsed fusion propulsion. This evolutionary approach makes LHPPP very attractive for development today. Systems for attitude control and orbital correction of geosynchronous satellites would provide the experience necessary to begin the development.

NASA and Aerojet Rocketdyne are designing **nuclear thermal rockets**, NTR, for near-term applications. Nuclear testing options were assessed by NASA Stennis Space Center and Aerojet-Rocketdyne engineers. Testing of the simulated nuclear fuel elements is underway at the NASA Marshall Space Flight Center. Small NTR stages for in-space testing were assessed.



NASA

NASA is assessing a small nuclear thermal rocket engine and stage for in-space testing.

Previously, NASA's Glenn Research Center, the U.S. Department of Energy and industry partners outlined a preliminary plan for design, development, test, and engineering for NTR stages for NASA headquarters that involved significant system-level demonstration projects. Included were ground test demonstrations at the **Nevada National Security Site**, followed by a flight test demonstration mission. To reduce development costs, the demonstration tests use a small, low-thrust-level (7,500 pound or 16,500 pound) engine. Both engines use graphite composite fuel and a "common" fuel element design that is scalable to higher-thrust, 25,000-pound engines by increasing the number of elements in a larger diameter core that can produce greater thermal power output. To keep the FTD mission cost down, a simple "1-burn" lunar flyby mission was considered along with maximizing the use of existing and flight-proven liquid rocket and stage hardware (e.g., from the RL10-B2 engine and Delta Cryogenic Second Stage) to further ensure affordability. The planning would lead to the flight of a small NTR engine and stage within a 10-year time frame.

In July, NASA Glenn for the first time presented detailed analyses of elements of aerial transportation for **atmospheric mining in the outer solar system**. The paper also focused on an outer planet exploration with gas core and fusion propulsion applications, including interstellar missions.

Helium 3 and deuterium would be the fuels wrested from the planets' atmospheres with a closed cycle gas core nuclear rocket mining aerospacecraft. Subsequently, the fuels would be transported to an outer planet moon for processing. Sizing of several transportation vehicles and their related systems was presented: moon base propellant factories, moon base landers, and orbital transfer vehicles. Preliminary mission planning and optimizations for atmospheric mining were detailed and travel times for orbital transfer vehicles from Uranus and Neptune to their respective ISRU moon bases were presented. Preliminary optimization results of the transportation system pointed toward at 10 megawatt nuclear electric orbital transfer vehicle and a 200 metric ton propellant-payload, oxygen-hydrogen propulsion moon lander.

Exploring combustion and supersonic flow

by Joanna Austin and Yiguang Ju

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.*

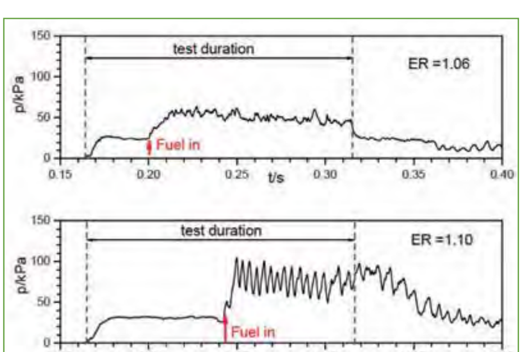
Two divisions within the U.S. Air Force's Aerospace Systems Directorate — High Speed Systems and Turbines Engines — collaborated to demonstrate the utility of an Nd:YAG **burst-mode laser system** to interrogate the ignition transient within a cavity flameholder (fueled with ethylene, C2H4) in a Mach-2 crossflow.

For this purpose the burst-mode laser was set up in the Research Cell 19 Supersonic Flow Facility and **configured to excite formaldehyde** using the frequency-tripled output (355 nanometer) of the laser. The output laser beam was formed into a probe sheet (about 50 millimeter high by 0.3 millimeter thick) that was positioned 10-millimeter from the leading edge of the cavity. The burst-mode laser was fired at 50 or 100 kilohertz, and so either 500 or 1000 pulses were delivered within the laser's 10-millisecond burst time; total energy per burst was limited to about 40 joules, and thus at 50 kilohertz the pulse energy was 80 millijoule.

An intensified complementary metal-oxide-semiconductor camera (framing at either 50,000 or 100,000 frames per second) was positioned adjacent to the tunnel to capture CH2O planar laser-induced fluorescence (PLIF), using a Schiempflug mount for off-axis imaging — during the cavity's ignition transient. These measurements clearly show the time evolution of cavity ignition (via the CH2O PLIF images) and indicate a strong correlation between fueling rate and the delay between the onset of ignition and stable combustion (roughly 5 ms with spark ignition).

More importantly, the work, involving high-bandwidth laser diagnostics, shows that the span-wise propagation rate and structure of the flame is highly dependent on both the fueling rate and ignition source.

At the Institute of Mechanics of the **Chinese Academy of Sciences**, full-scale scramjet tests were carried out at duplicated hypersonic flight conditions in the JF-12 hypersonic shock tunnel. This Chinese facility is about 275 meters in length with a nozzle exit diameter of 2.5 meters, and is capable of reproducing air flows of more than 100 millisecond test duration for Mach numbers from 5-9 at 25 to 50 kilometer altitude to meet the requirement of full scale integrated hypersonic vehicle tests and study of high temperature gas dynamics. **Scramjet tests** were completed with the performance test engine, which is 2.2 meters long and consists of an inlet, a combustor and an expansion nozzle. The combustor is made with two cavities and fuel injections are distributed between the cavities for heat release control. The nozzle is two-dimensional and 1.5 meters in length. The test flow is Mach 7 with total temperature of 2200 kelvin and dynamic pressure of 50 kilopascal. Two operation modes were found for the test engine. In one mode, the pressure profile measured by distributed pressure transducers is flat with slight perturbations indicating stable combustion. In the other mode, periodical pressure oscillations at about 200 hertz were observed. The equivalence ratio is only the difference between the two tests. This important phenomenon could be defined as the engine surging and is a critical issue for scramjet operation control. High speed images show that the high-temperature gas is not observable when a shock wave is digested from the inlet. Most of the scramjet tests were conducted in combustion-based test facilities so that the experimental data at duplicated hypersonic flight condition would be of fundamental importance for exploring coupling of combustion, supersonic flow and shock dynamics.



Institute of Mechanics, Chinese Academy of Sciences/Zonglin Jiang

Pressure variations recorded in a combustor; top image shows stable combustion at ER=1.06 and the other shows unstable combustion at ER=1.10.

Institute of Mechanics, Chinese Academy of Sciences/Zonglin Jiang

A section of China's JF-12 hypersonic shock tunnel, which was built to replicate flight conditions for air-breathing hypersonic vehicles.

Solids rockets for space and missile defense

by Barbara Leary, Rob Black, and Agostino Neri

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.*

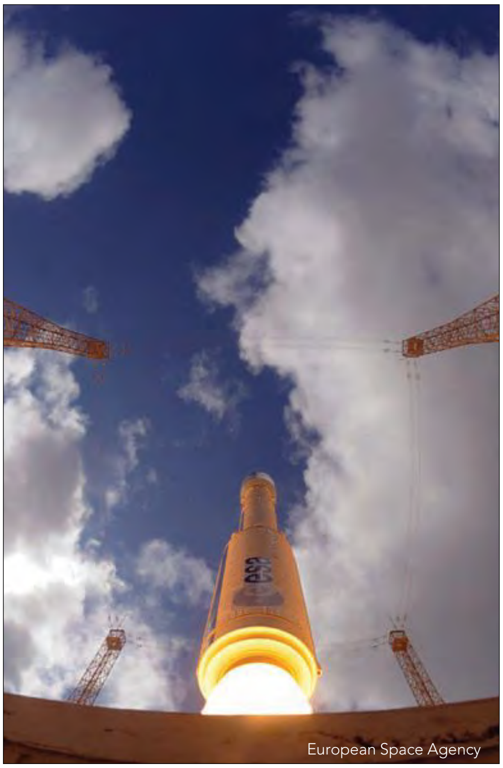
This year saw several notable flight tests and milestones of technology advancements and sustained production in solid rockets.

Lockheed Martin demonstrated its multimode **Joint Air-to-Ground Missile** engaging two laser-designated stationary targets during government-led flight tests at Eglin Air Force Base in Florida. The U.S. Army and the **Javelin Joint Venture**, comprising Raytheon and Lockheed Martin, conducted live-fire Javelin missile engagements against tank targets from different launcher and platform configurations, displaying extended range and versatility. In addition, the 40,000th Javelin missile system was delivered to the U.S. Army.

In June the U.S. Navy and Raytheon completed operational testing and evaluation live fires of the AIM-9X Sidewinder Block 2 infrared air-to-air missile. Testing and evaluation consisted of 16 planned shots against a mix of full-scale and sub-scale targets.

Aerojet Rocketdyne delivered the 200th booster motor and Divert and Attitude Control System for the **Terminal High Altitude Area Defense weapon system**. Aerojet Rocketdyne supplies both propulsion systems.

The U.S. Navy and Missile Defense Agency conducted the first flight test of the Raytheon Standard Missile-3 Block 2A interceptor. The interceptor has larger rocket motors to add increased kill capability over wider regions. The mission, Control Test Vehicle-01, evaluated the SM-3 Block 2A's nose cone performance, steering control section function, booster separation, and second and third stage rocket motor separation.



The European Space Agency's Intermediate Experimental Vehicle atop a Vega rocket. A new Zefiro 40 solid rocket motor will propel the second stage of a more powerful version of Vega now in development.

In a first-of-its-kind test, the U.S. Navy in July fired a Raytheon Standard Missile-6 Dual 1, intercepting and destroying a short-range ballistic missile target at sea. The test showed that a modified SM-6 can eliminate threat ballistic missiles in their final seconds of flight.

The launch-systems area also recorded significant progress this year. NASA's Exploration Flight Test-1 launched from Cape Canaveral, and jettisoned the Lockheed Martin-built spacecraft using the Orion jettison motor built by Aerojet Rocketdyne.

Vega, the European launch system developed by the Italian company ELV and operated by Arianespace, performed three flights maintaining the objectives of the 2015 launch manifest. Vega is composed of three solid propulsion stages manufactured by **Avio Spazio**: P80, Zefiro 23 and Zefiro 9.

Ariane 5 launch system, using two solid propellant boosters built by Europropulsion — a joint venture between Avio and Airbus Safran Lanceurs — continued to prove to be a robust and reliable workhorse, reaching more than 65 consecutive successful missions. In addition, following the decisions of the 2014 European Space Agency's Ministerial Conference, the development of two high-performance solid rocket motors, namely P120C and Zefiro 40, that will power the new Ariane 6 and Vega Consolidated (Vega C) launch vehicles, has begun.

Orbital ATK, formed by the merger of Orbital Sciences and the Aerospace and Defense Groups of Alliant Techsystems in February, supported a GPS 2F-9 satellite launch on board a **Delta 4 medium-plus rocket** in a configuration featuring two commercial GEM-60 solid rocket motors. These were the 43rd and 44th GEM-60s to fly.

This year was the 25th anniversary of the first flight of the **Pegasus air-launch rocket**. To date, Pegasus has conducted a total of 42 space launches, including 28 consecutive successes over the past 18 years.

Orbital ATK conducted the first qualification test of the five-segment solid rocket motor that will be used for NASA's heavy-lift Space Launch System. The motor produced 3.6 million pounds of thrust and burned for just over two minutes. The rocket is the largest human-rated rocket built today.

Energy engineering with frontier additive manufacturing

by Ahsan Choudhuri and Ryan Wicker

*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.*

Additive manufacturing is a frontier technology that could revolutionize the way energy-system components are designed and fabricated. Recent innovation in additive manufacturing processes for metal, such as laser and electron beam melting, have opened ways to produce novel components. They include highly geometric, complex parts such as fuel injectors and pumps made in one step. This year, NASA tested the first-ever **3D-printed turbopump** with liquid hydrogen propellant and the FAA certified the first 3D-printed component for commercial jet engines.

Metal additive manufacturing processes pose the innovation in design renaissance for layer-by-layer fabrication of complex, custom metal or alloy energy system components impossible to achieve by more conventional processing of wrought or cast. Additionally, metal AM processes allow embedding or integrating sensors in complex energy system components without the modification of the component post-production.

In addition, metal additive manufacturing has made possible wholly new approaches to component design. One example is the ability to integrate parts with sensors for monitoring aircraft health and performance. The lack of assembly requirements, along with virtually unlimited possibilities for geometrical complexity, make additive manufacturing methods particularly attractive for fabricating multi-functional parts that can operate under extreme environments, whether high temperatures or pressures, as well as highly reducing or oxidizing atmospheres.

Investigators of the W. M. Keck Center for 3D Innovation and NASA MIRO Center for Space Exploration Technology Research, both based at the University of Texas at El Paso, are developing complex combustor components with embedded sensors using metal additive manufacturing. The UTEP group this year embedded **piezoelectric sensors** in an additively-manufactured component by using a stopping-and-restarting process with electron-beam melting.

To take full advantage of the unique capabilities of the technique, components have to be designed within the constraints and abilities of the 3D-build process. Various designs of energy-system components, such as fuel injectors with intricate internal cavities, have to be carefully evaluated to make them amenable to additive manufacturing. EBM, a Mölndal, Sweden-based company that makes metal additive-manufacturing equipment, recently established new methods to help set parameters for working with **novel high-temperature super alloys**.

Researchers at the University of Texas at El Paso have outlined several challenges — mostly materials-related — that still need to be overcome in order for electron-beam melting to become a mainstream additive technique and possibly the technique of choice for fabricating parts aimed at functioning under environmental extremes of most energy systems.

First, the range of **raw-powder materials** commonly used to make metal parts through additive manufacturing is limited to just a few metals and alloys. Secondly, the effect of the processing parameters, raw powder characteristics and post-processing treatment on the structural, chemical and mechanical properties of the part and its ability to withstand extreme environments are not well established. There is an apparent need for exploring alternative metal AM materials via novel syntheses and powder modification processes, as well as for comprehensive investigations based on computer-simulation predictions validated by processing-characterization experiments. Investigations should be aimed at understanding and eventually controlling the parameters that dictate the properties of the parts fabricated by metal additive manufacturing.


NASA/MSFC/David Olive

NASA engineers prepare a 3D-printed turbopump for a test at NASA's Marshall Space Flight Center in Alabama.

Eating lettuce grown in space

by Joe Chambliss

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

The NASA Advanced Exploration Systems Life Support Systems team is addressing environmental control and life system technology gaps, the goal being to improve reliability and further close the air and water recovery loops. The team is also advancing toward integrated ground testing and ISS testing. Milestones completed this year include a spacecraft atmosphere monitor systems requirements review; alternate sorbent and desiccant selection and testing for CO_2 removal; cascade distillation system critical design review; validation and advancement of a combustion products monitor; and incorporation of autonomous controls in life support subsystems.

NASA's test of the **Amine Swing Bed** for carbon dioxide removal continued on ISS.

The one-year mission began on ISS with the March 25 launch and docking of a **Soyuz capsule** carrying crew members Scott Kelly and Mikhail Kornienko. In-flight data collection in support of human research program investigations is underway. A space human factors and habitability study will systematically review how microgravity and gravitational transitions affect crew members' fine motor skills.

The first successful human tests of Portable Life Support System (PLSS) 2.0, for future space suits were completed marking the first time a NASA-developed PLSS has been built using advanced technologies, packaged into a representative volume, and tested with a human in the loop since the 1970s. Tests demonstrated that PLSS 2.0 and supporting test system can maintain a safe environment in the Mark 3 space suit.

NASA's Johnson Space Center, which manages research on new spacesuit designs, completed the fourth and final suited evaluation in the 2015 **Vacuum Pressure Integrated Suit Test** in March. Four suited events evaluated the integrated performance of Orion's vehicle environmental control and life support system hardware under flight-like conditions in the Building 7 11-foot vacuum chamber. The Orion ECLSS system was the sole provider of life support to two test subjects, providing 100% oxygen and carbon dioxide removal.

NASA

One small bite for man, one giant leaf for future space explorers. Astronauts this year grew — and ate — lettuce in the International Space Station.

NASA hosted a planetary protection workshop in March at Ames Research Center. Since the last workshop in 2005, the capability of genomic sequencing now allows thorough characterization of microbes.

The European Union ISS **Antarctic Greenhouse Module Project** started in March with 13 partners from across Europe. The project will deploy a plant production facility to the German Neumayer 3 Antarctic station in 2017 which will include both an ISS full-rack plant growth demonstrator as well as a larger compartment representative of early planetary surface systems. The project will provide overwintering crews with fresh produce. It will advance the technology readiness of controlled environment agriculture technologies and biological life support operational procedures for flight.

Google executive Alan Eustace made history with his parachute jump from the stratosphere.

Paragon Space Development Corp.

The ISS crew was given approval this year to consume a **lettuce crop** grown on the station in a compact, low-power chamber called Veggie. On August 10, Scott Kelly, Kjell Lindgren and Japanese astronaut Kimiya Yui enjoyed space-grown red romaine lettuce, which was the first produce grown on ISS that the crew was allowed to eat, much to their delight.

Veggie advances knowledge of space horticulture by developing low-energy, simple methods to grow a variety of crops with the goal of supplementing astronaut diets with variety and keeping our explorers connected to Earth.

The suit **Google executive Alan Eustace** wore for his record-setting dive from a parachute from near the stratosphere in October 2014 was accepted by the Smithsonian National Air and Space Museum. The self-contained, 5.3-pounds-per-square-inch-absolute pressurized spacesuit was custom made by ILC Dover; its PLSS and spin stabilization system designed by Paragon Space Development Corp., and the parachute system was developed by United Parachute Technologies.

The dive was a finalist for the **2015 Collier Prize**.

Levitation study starts on space station

by Michael P. SanSoucie, Robert D. Green and Michael C. Hicks

*The **Microgravity and Space Processes Technical Committee** encourages the advancement and public awareness of low-gravity studies in physics, materials, biological sciences and related fields.*

In July, the European Space Agency launched the **Materials Science Laboratory Electromagnetic Levitator** to the International Space Station, where it is operating in the European Columbus laboratory. Electromagnetic levitation provides a unique way to study electrically conducting samples, such as metals and semiconductors, free from the influences of surface contacts. The MSL-EML uses copper coils to levitate and heat samples without the interference of a container or data-gathering instrumentation. This will allow the formation of free floating liquid droplets over a wide range of temperatures, above and below the material's melting point, providing access to physical states otherwise impossible to achieve in 1-G environments.

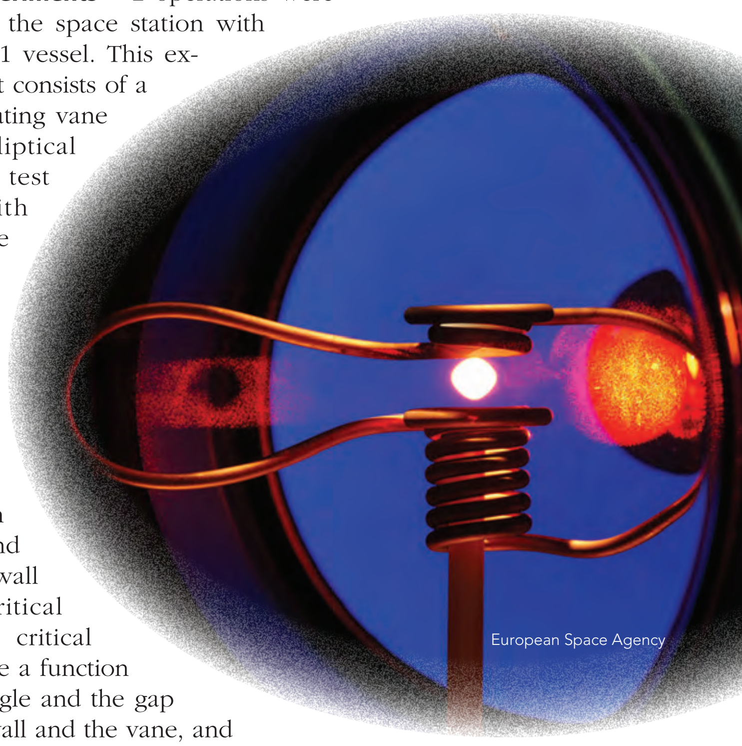
For example, undercooling — an important non-equilibrium state in material science studies when the material remains in the liquid phase at temperatures below its melting point — can be achieved at lower temperatures for longer. This containerless type of processing will allow for precise, undisturbed measurements of the thermophysical properties of molten metals; such properties include surface tension, viscosity, density and conductivity of the material over a wide range of temperatures.

Droplet combustion experiments performed in the flammability and extinguishment experiment (FLEX) continued on the ISS. Single **droplet experiments** with decane, a constituent of gasoline, provided the first visual evidence of a cool flame, or barely perceptible flames that burn at a third to half the temperature of normal flames and which have far reaching implications for a number of combustion technologies. Recent droplet experiments showed that it is possible to directly ignite a cool flame without going through a progression from hot flame to radiative extinction to cool flame — something previously believed necessary. Additional experiments involving binary droplet arrays also exhibit cool flame burning. These experiments result in a large "envelope flame" surrounding the two droplets. Because of the larger flame structure, a higher radiative loss causes a radiative extinction to occur at much smaller droplet sizes. This promotes an earlier transition into the cool flame regime and has interesting implications with spray combustion.

The FLEX experiments have renewed interest in the combustion community in low-temperature combustion processes. This includes efforts in theoretical and numerical modeling for estimating burning rates, flame standoff ratios and extinction diameters for the droplet configuration. **Ketohydroperoxides** have been identified as the key intermediate reaction species that determines the chemical kinetic pathway during combustion of straight chain alkane fuels.

Insights from this year's experiments and analyses are being used to formulate test parameters for a follow-on ISS experiment, the **cool flame investigation**. This will investigate a range of other fuels, including biofuels, to better understand low-temperature chemistry and its relation with recent observations of the cool flame phenomenon.

In the fluid physics discipline, further **capillary flow experiments** — 2 operations were performed on the space station with the vane gap 1 vessel. This experimental unit consists of a perforated rotating vane inside an elliptical cross-section test chamber with 10 centistoke silicone oil as the working fluid. When the vane is rotated, the silicone oil "wicks" up the vane at the intersection of the vane and test chamber wall at certain critical angles. These critical vane angles are a function of both the angle and the gap between the wall and the vane, and whether the vane perforations are open or filled with fluid. In this year's investigation, these critical vane angles were characterized for several "patterns" of open and filled vane perforations. The CFE-2 experiments have shed significant light on moving capillary boundary conditions, passive capillary migration, passive bubble separation, and critical geometric wetting, and find application in fluids management aboard spacecraft including passive phase separations, urine collection systems, and condensing heat exchangers — for both NASA and the U.S. commercial aerospace industry. Terrestrial applications include **microfluidics for bio-sensing**, medical tubing and even candle wicks.



The Materials Science Laboratory Electromagnetic Levitator is operating in the European Columbus laboratory at the International Space Station.

Air and missile defense make strides

by Jeff Scott, Edward Eiswirth and Mark Friedlander

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

This year saw continued advancement of several missile technologies, particularly in air and missile defense systems.

Significant improvements to the U.S. air-to-air missile inventory came when Raytheon's **AIM-9X Block 2** reached initial operation capability in March and the AIM-120D achieved the same in April.

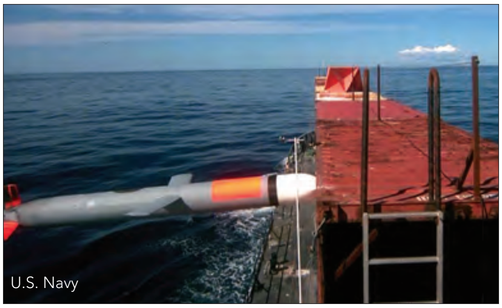
The AIM-120D advanced medium range air-to-air missile has 50 percent greater range and improved navigation than its predecessor, thanks to a new rocket motor and addition of GPS. These upgrades plus a two-way datalink and improved high off-boresight capability increase no-escape boundaries and enhance probability of kill.

AIM-9X Block 2 enhances the Sidewinder air-to-air-missile with improvements in seeker performance, infrared counter-countermeasures, kinematics and lock-on after launch supported by a datalink for beyond-visual-range engagements. Further enhancements are underway in the Block 3 program to replace the rocket motor and warhead for increased range and lethality. The missile is being integrated onto a variety of aircraft, including the F-35, for the U.S. Air Force and the Navy, as well as for international customers.

A Raytheon Standard Missile SM-6 Dual 1 variant was test fired from the USS John Paul Jones to intercept a ballistic missile in the final phase of flight.

The U.S. Army is also testing AIM-9X Block 2 with its multi-mission launcher. Successful launches against an unmanned aircraft at the White Sands Missile Range in New Mexico in April and over the Navy's China Lake test range in California in August demonstrated AIM-9X's capabilities as a ground-based air defense system. The multi-mission launcher, a modular launcher for up to 16 interceptors, has been further tested with Lockheed's **Miniature hit-to-kill vehicle** to demonstrate a low-cost counter-rockets, artillery and mortars capability.

At the other end of the air-defense spectrum lies the challenge of defeating ballistic missiles. In July, the U.S. Missile Defense Agency launched the latest variant of Raytheon's **Standard Missile-6, called Dual 1**. This "dual mission capable" variant can engage relatively low speed targets like aircraft and cruise missiles as well as ballistic missiles. The test demonstrated Dual 1's active seeker and improved targeting software to identify, track and kill a ballistic warhead descending from the upper atmosphere at extreme speed. Part of the U.S. Navy's integrated air and missile defense strategy, SM-6 and the Lockheed Martin **Aegis Combat System** are able to identify and destroy threats from beyond the radar horizon. Powered by Aerojet first- and second-stage rocket motors, SM-6 can also engage land targets using GPS.



A Tomahawk cruise missile hits a moving target after receiving position updates from surveillance aircraft.

Overseas, Australia demonstrated a wing kit for Boeing's **Joint Direct Attack Munition**. This extended range variant triples the range of the GPS-guided bomb by adapting technology from Boeing's Small Diameter Bomb increment 1. SDB 1 itself has been heavily used by the U.S. Air Force during the air campaign in Iraq and Syria.

The year also saw continued anti-ship missile development. Navy engineers demonstrated new applications for the **Tomahawk cruise missile** by modifying existing datalinks and sensors to communicate over the same network. During a January test, a 'synthetically guided' Tomahawk launched from USS Kidd off California. While the missile was in flight, a surveillance aircraft transmitted real-time location data of a moving ship to China Lake, California, which relayed the information to the Tomahawk via its existing two-way satellite datalink. The test demonstrated the missile's ability to alter course and hit a moving target without an onboard seeker, using only position updates from the surveillance plane.

Meanwhile in strategic systems, June marked the 45th anniversary of **Minuteman 3** operations. Among the Air Force operational evaluations performed in 2015, prime contractor Boeing supported testing of an unarmed Minuteman 3 launched from Vandenberg Air Force Base in California, as directed by crewmembers aboard an E-6B Airborne Command Post aircraft. The intercontinental ballistic missile traveled 4,200 miles to its target in the Pacific, verifying accuracy and reliability to ensure Minuteman remains an effective deterrent.

Expandable space habitats ready for launch

by Maria Joao Durao, Barbara Imhof, Donald Barker, Mark Kerr, and Sandra Haeuplik-Meusburger

*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.*

Between 1950 and the early 1990s NASA investigated several inflatable or expandable space structures, most notably the **Transit Habitat (Transhab) module**. Following its cancellation, Bigelow Aerospace purchased the rights to this technology. To date, Bigelow Aerospace has flown two pathfinder spacecraft and — after a roughly two and a half year development, fabrication, and testing cycle — has developed the **Bigelow Expandable Activity Module**.

BEAM, now being prepared for launch at Kennedy Space Center, will be transported to the International Space Station within the trunk of the upcoming SpaceX CRS-8 resupply flight. Once berthed to the ISS, BEAM will deploy to provide 16 cubic meters of volume and act as a technology demonstration platform for validating material and structural interactions in the space environment. BEAM, the first expandable space structure used for long-duration human habitation in space, will remain on orbit for a minimum of two years.

Bigelow Aerospace has grander plans for space structures, including their B330 module; encompassing a volume of 330 cubic meters it will support a crew of six. Additionally, in July, NASA and Bigelow Aerospace signed up to cooperatively develop concepts for using the B330 in support of crewed missions to the Moon and even Mars.

In an effort to explore human missions on Mars, habitation options were explored under the NASA **Human Spaceflight Architecture Evolvable Mars Campaign**. In particular, a modular habitation system was devised that can be applied to planetary surface and deep space human exploration missions. Small cabins derived from the modular system can fit into the Space Launch System Orion "trunk" or can be mounted with mobility systems to function as pressurized rovers, in-space taxis, ascent stage cabins or propellant tanks. Larger volumes could also be created using inflatable elements for long-duration deep space missions, and planetary surface outposts.

This year marks the conclusion of the **Self-Deployable Habitat for Extreme Environments**, SHEE, project, a three-year effort developed under the European Commission's Seventh Framework Program. Space architecture companies, LIQUIFER Systems Group of Austria and Space Innovations of the **Czech Republic**, helped develop the project along with five other European institutions and companies. SHEE is the first deployable habitat simulator to be designed and constructed in Europe and is now available to the larger research community for conducting simulations. Distinctive features of the SHEE project include its easy transportability with a flatbed truck and its capacity to automatically deploy — increasing the size of the habitat and usable space to accommodate a crew of two. The habitat is outfitted with interior furnishings permitting different usage and activity by crew members, including sleeping cabins, a work area, a multi-functional common area, hygiene compartment and small workshop. SHEE's environmental control and life support system can sustain a two-person crew for two weeks. The SHEE habitat can be placed in various environments for simulation testing ranging between Antarctica (-60 Celsius) and in the desert (50 Celcius). The habitat is ideal for conducting scientific research on the affects of confinement and for testing space-related systems and technologies.

An artist's rendering shows the Bigelow Expandable Activity Module attached to the International Space Station.

The Self-Deployable Habitat for Extreme Environments, SHEE, the first deployable habitat simulator to be designed and constructed in Europe, concludes a three-year project in 2015.

Robotic refueling displays new tools for satellite servicing

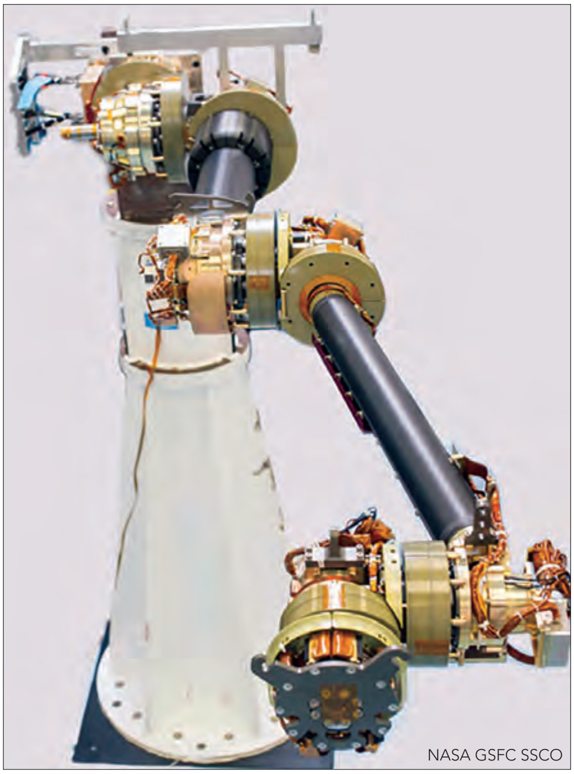
by Gardell Gefke, Kate Stambaugh and David Spangler

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

Space automation and robotics continued to make steady technical and in-space demonstration progress throughout 2015.

The **Satellite Servicing Capabilities Office** (SSCO) at NASA's Goddard Space Flight Center made strides in technology development in 2015. On orbit, the second phase of Robotic Refueling Mission (RRM2) operations took place during April and May on the International Space Station.

First, two new RRM2 task boards were robotically transferred and installed onto the RRM module. Once this hardware was in place, RRM2 demonstrated the **Visual Inspection Poseable Invertebrate Robot** (VIPIR), a multi-capability inspection tool. VIPIR carries an 8mm-24mm optical motorized zoom lens, as well as a 1.2mm camera mounted on the end of an extendable, articulating borescope. RRM2 science operations were conducted in October and are scheduled to be completed in December. Since its launch in 2011, RRM has been demonstrating new tools, technologies and techniques for satellite servicing, using the space station as a testbed.

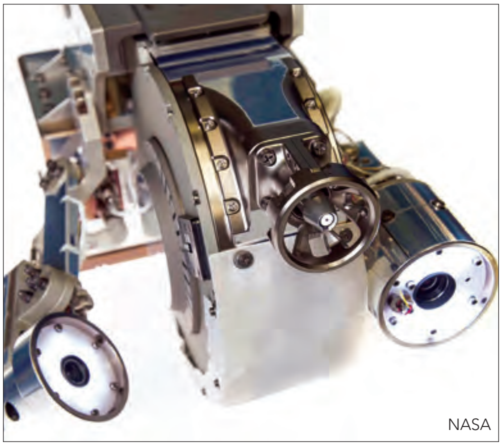


In June, the Goddard Space Flight Center received the first engineering design unit of a robotic arm for on-orbit satellite servicing and asteroid capture.

In June, the SSCO received the first **engineering design unit** (EDU) of the NASA Servicing Arm system, a 2-meter class, seven-degree of freedom robot arm that can be used on missions as diverse as on-orbit satellite servicing and asteroid capture.

In late summer, a new robotic servicing development center was established at Goddard. The facility will focus on maturing the technologies required for successful in-space robotic operations, including dedicated robotic work cells for EDU robot arm development, autonomous grasp, asteroid retrieval and satellite servicing.

In August, DARPA awarded a contract to Space Systems/Loral for the **Dragonfly** program. The Dragonfly concept, which is designed to have both military and commercial applications, is for satellites to self-assemble from an efficiently stowed state while in orbit with a focus on the installation and reconfiguration of large radio frequency antenna reflectors.



The Visual Inspection Poseable Invertebrate Robot was operated during the second phase of the Robotic Refueling Mission on the International Space Station.

DARPA's **Phoenix geosynchronous Earth orbit** (GEO) servicing program continues to advance robotic technologies in three main areas: Advanced GEO serving robotics for assembly repair and asset life extension; satlets, independent modules with essential satellite functionalities, which can independently or in aggregate accomplish a wide range of satellite missions; and the Payload Orbital Delivery System as a standard way to safely carry separable mass elements to orbit, particularly GEO.

NASA Langley continues to advance the **Tendon-Actuated Lightweight In-Space MANipulator** (TALISMAN) long-reach robotic manipulator architecture concept. TALISMAN uses tendon actuation, which can be semi- or fully-antagonistic, with major components being the link, spreader, lightweight cables, motors and gearboxes. These increase joint stiffness due to tendon architecture, and produce lightweight joints enable the number of joints to be optimized to achieve desired packaging efficiency, range-of-motion and dexterity. The architecture has potential applicability to the ARRM and other large in-space satellite assembly concepts.

SkyFire was selected in April 2015 by NASA's **NextSTEP** program (Next Space Technologies for Exploration Partnerships) and awarded a contract to Lockheed Martin space systems. As proposed, the nanosatellite spacecraft would fly by the Moon and collect surface spectroscopy and thermography. Its purpose is a GEO technology demonstration using low-cost 6-unit cubesat spacecraft. The cubesat would include deployable solar arrays and have a total mass of about 14 kg.

Unified paths to future space settlements coming to clearer focus

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.*

Many good steps were taken in 2015 toward expanding the human economy throughout cislunar space. Although we have yet to see unified planning of integrated infrastructure components to enable future space settlement, paths to developing bits of infrastructure that can help achieve that goal are becoming more apparent.

The **International Space Station** remains the main focus of commercialization. Multiple vehicles are delivering cargo, and the SpaceX Dragon capsule enables return of experiment results and hardware. SpaceX attempted soft landings of launch vehicle first stages in order to enable reusability and reduce costs. Both SpaceX and Orbital ATK suffered launch failures this year.

ISS was staffed with only three crew for several months in order to conserve supplies; a full crew of six was restored in order to better understand effects of long-term spaceflight on the human body. The **Commercial Resupply Services** contracts for SpaceX and Orbital are ending soon, and NASA requested bids for the CRS2 contract. Several challengers to the incumbents submitted proposals; announcement of contract awards is pending.

SpaceX and Boeing are making progress toward restoration of U.S. capability to launch astronauts to ISS, through the Commercial Crew Program. Test flights remain scheduled for 2017.

Commercialization of ISS services through the nonprofit **Center for the Advancement of Science in Space** has made ISS more valuable as a national laboratory, including launches of cubesats from an airlock on board.

Cubesats are proliferating way beyond what most of the industry would have predicted only a few years ago. Miniaturization of electronics and instruments enables these tiny independent satellites to perform a variety of tasks and services. These can be launched "piggyback" with primary payloads on large launch vehicles, or can be lofted to orbit with smaller and less expensive launch vehicles. Their relative low costs, speed of development and versatility are attracting nontraditional customers.

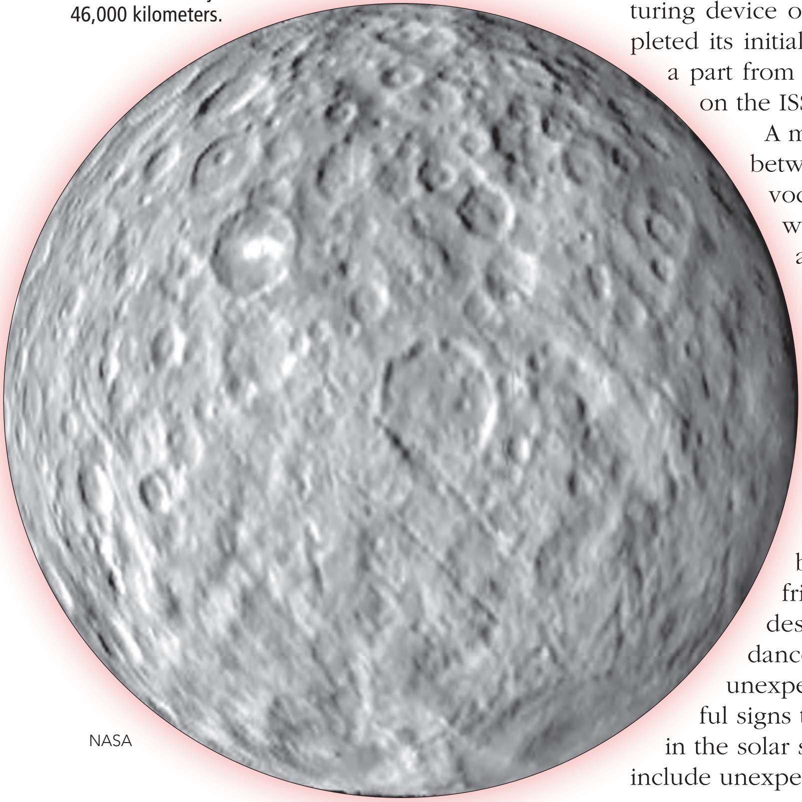
In August, **NanoRacks** of Texas and Made In Space of California announced a partnership to assemble cubesats on the ISS for commercial clients. Interest in Solar Power Satellites continues to grow, with tracks of sessions at major conferences, and international meetings specifically on this topic.

In September, **Made In Space**, along with NASA, launched the first additive manufacturing device off planet. The machine completed its initial mission phase by uplinking a part from the ground and producing it on the ISS in a matter of hours.

A major step toward cooperation between space technical and advocacy organizations was made with the founding of the Alliance for Space to advocate for increased human presence in space. The Space Frontier Foundation and the National Space Society are the two key members.

The most spectacular achievements in space in 2015 were flybys of dwarf planets **Ceres** in the asteroid belt, and Pluto on the inner fringes of the Kuiper belt. Each destination provided an abundance of surprises in bizarre and unexpected terrain, providing hopeful signs that venturing to more places in the solar system can find surprises that include unexpected new resources, too.

The surface of Ceres composed of images captured by NASA's Dawn spacecraft in February from a distance of nearly 46,000 kilometers.



NASA

Space predictions start to come true

by Franz Newland and Paul Douglas

The ***Space Operations and Support Technical Committee*** *focuses on operations and relevant technology developments for manned and unmanned missions in Earth orbital and planetary operations.*

This has been an interesting year if one looks back to **past predictions for the field of space operations**.

In 2006, for instance, the U.S. Army issued plans for space operations for 2015 and beyond. A number of concepts were raised, including the need for much stronger joint-agency operations, the use of commercial space assets, and the potential for small, responsive spacecraft to meet operational needs.

Nine years later (relatively brief time in the space industry) all three concepts have largely been borne out. In June, the U.S. Department of Defense agreed to set up a joint space center that would **track both military and spy satellites** for the first time. Meanwhile, commercial space operation activities marked a number of significant firsts this year, including NASA's announcement of its first commercial crew astronauts.

This year saw the long-awaited arrival of the New Horizons mission at Pluto after more than 3,400 days in transit. This unusually long flight time constitutes a record for a mission to reach its primary target and certainly a triumph for the flight operations team at **Johns Hopkins University's Applied Physics Laboratory**.

"Operationally, one of the major challenges was the long round trip light time delays at encounter — nine hours — that forced us to institute a great deal of autonomy aboard the spacecraft," says Alan Stern, the mission's principal investigator.

A SpaceX Falcon 9 rocket and Dragon spacecraft break apart shortly after liftoff at the Cape Canaveral Air Force Station on June 28.

Associated Press

Stern's flight team guided the spacecraft through multiple encounters and hibernation cycles throughout its long journey, and in that time, the only major upset was a brief slip into safehold mode, from which they recovered after only one hour and twenty minutes. Of all the records this mission has set so far, the marathon leading to Pluto's arrival is the most striking from the operations perspective and may well remain the pinnacle achievement for decades to come, with no future missions slated for the outer solar system currently.

On the commercial operations front, NASA named its first four commercial crew astronauts,

NASA/Bill Ingalls

Members of the Johns Hopkins University Applied Physics Laboratory flight operations team and guests count down in July to New Horizons' approach to Pluto.

who will train with their commercial colleagues for the Dragon and CST-100 vehicles. In parallel, Congress passed the Spurring Private Aerospace Competitiveness and Entrepreneurship Act this year, which updated a number of elements of **commercial space law**, including extending security for U.S. companies against any third-party losses after a catastrophic launch failure and limiting FAA regulation around the still infant commercial human spaceflight industry.

Internationally, Japan also started considering legislation in 2015 to allow private spaceflight initiatives. Commercial space endeavors also led the way in remote sensing, with **DigitalGlobe** providing full access to their 30 cm imagery, U.K.'s Surrey Satellite Technology launching its DMC3 spacecraft to provide 1 meter resolution imagery from a smallsat platform and Canada's Urthecast providing incredible HD video from the space station. Surrey Satellite also opened its new spacecraft operations center, expanding its commercial spacecraft operations services, and Analytical graphics' Commercial Space Operations Center, which provides a commercial space situational awareness, SSA, service, was awarded its first contract to provide SSA data to Boeing for launch and early operations activities for its **all-electric propulsion geostationary satellites**. Such capabilities demonstrate the potential for commercial innovation in space operations.

The commercial space story in 2015 would not be complete without mentioning the SpaceX Falcon 9 failure. The longer-term effects of this, if any, are still unknown. However, as Congress' actions regarding the SPACE Act earlier this year appear to recognize, this commercial industry is young, and still trying to strike the right balance between acceptable and unacceptable risks.

Preparing for manned and unmanned space exploration

by William G. Tomek and Daniel W. Kwon

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

While NASA and industry pursue a domestic crew-transportation capability for low-Earth orbit, advances have been made in exploration-mission planning and launch-vehicle and spacecraft development for manned and unmanned systems.

In July, experts from around NASA completed an 11-week-long critical design review of the Space Launch System launch vehicle at Marshall Space Flight Center in Alabama. The review focused on **SLS Block 1**, the version of the rocket that will launch an Orion crew capsule on Exploration Mission-1, an unmanned flight to demonstrate the seamless integration of the crew spacecraft and rocket. A key SLS milestone was achieved in March, when a test version of the vehicle's solid rocket motor roared to life in the desert scrub of Orbital ATK's Promontory, Utah, facility. Orbital ATK disassembled and inspected the rocket, called Qualification Motor-1, and declared the static test a "resounding success."

Progress continued on the **liquid-hydrogen-fueled RS-25 engines** for SLS. Test firings on an initial version of these upgraded space shuttle engines were conducted at Stennis Space Center in Mississippi in anticipation of the first ground tests with flight engines.

In the world of commercial launch vehicles, SpaceX tried a second time to land a Falcon 9 first stage on a platform in the Atlantic Ocean. The company planned to make a third attempt once the Falcon 9s were cleared to fly again after the June failure of a cargo mission to the space station. In April, United Launch Alliance announced development of a new rocket to be called Vulcan, whose Blue Origin-provided BE-4 engines eventually will be recovered and reused. Airbus this year unveiled plans to return rocket engines to Earth inside a winged vehicle to be called **Adeline**. Aerojet Rocketdyne and Blue Origin conducted research toward allowing the U.S. to launch rockets independently of Russian technology.

The March ground test of Orbital ATK's five-segment rocket motor, known as QM-1, was a key milestone for NASA's Space Launch System.

NASA/Orbital ATK

In the small-satellite industry, firmer plans emerged for several proposed low-Earth-orbit constellations. In June, OneWeb announced that Airbus will build more than 900 satellites for its planned constellation of broadband satellites, with the first to be launched in 2018. OneWeb also placed the largest commercial launch order to date, contracting with Arianespace and Virgin Galactic for a combined total of 60 satellite launches worth about $500 million. That same month, Seattle-based BlackSky Global announced plans for a 60-satellite Earth imaging system, with the first launches planned for late 2015. In July, Planet Labs acquired BlackBridge of Berlin, Germany, and its RapidEye constellation of satellites to accelerate its growth in the Earth observation market.

The emerging marketplace for commercially operated weather satellites saw San Francisco-based Spire send four cubesats to orbit in September to detect **automatic-identification-system beacons** from ships under the company's plans to deliver maritime services, including weather data.

NASA

NASA's Space Launch System is undergoing wind-tunnel tests, including at the Langley Unitary Plan Supersonic Wind Tunnel in Virginia.

While early planning continued for a human journey to Mars in the 2030s, NASA managers are analyzing possible interim missions between low-Earth orbit and Mars. To set the stage for more detailed Mars exploration, the **Curiosity rover** continued ground-breaking science on the surface of the planet. Those findings will sharpen planning for future robotic sample return missions and manned missions after that.

On the **Asteroid Redirect Mission**, NASA chose to capture a boulder off a large asteroid and deliver it to a lunar retrograde orbit for rendezvous with a subsequent human mission via the SLS and Orion.

A study is underway on a possible unmanned mission to **Jupiter's moon Europa**, whose icy exterior is thought to cover an ocean of liquid water that could harbor a simple form of life.

After traveling through space for almost 10 years, the **New Horizons spacecraft flew by Pluto** and its moon, gathering images and data that will continue to arrive well into 2016.

Preparing for a busy 2016 for space tethers

Sven G. Bilén

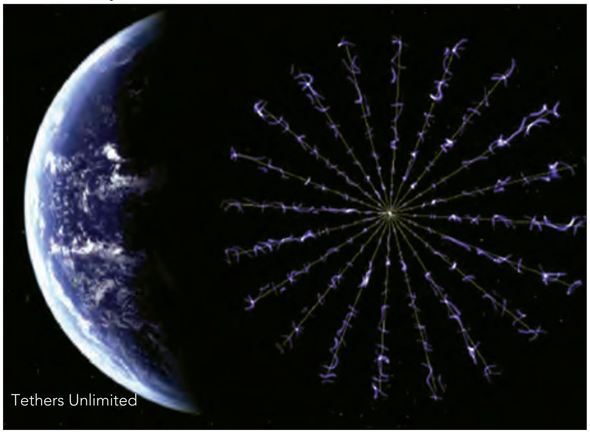
*The **Space Tethers Technical Committee** focuses on the development and use of tether-based technology for space systems.*

The space tethers community this year began preparing in earnest for several upcoming missions while continuing to develop new technologies and explore mission concepts.

JAXA, the Japan Aerospace Exploration Agency, is planning a late 2016 flight demonstration of an electrodynamic tether (EDT) called the **Konotori Integrated Tether Experiment**, or KITE. KITE will be integrated on an H-2 Transfer Vehicle to demonstrate key technologies for active debris removal using electrodynamic tethers. A zenith-deployed 700-meter-long, bare tether will collect electrons from the ambient space plasma, and a field-emission cathode on the transfer vehicle will emit 10 milliamperes of current to provide propellant-free deorbit propulsion. KITE is currently in the flight-model testing phase.

In Februray and May, Tethers Unlimited delivered several **Nanosatellite Terminator Tether** (nTT) modules for missions scheduled to launch in 2016. Those missions include Georgia Tech's PROX-1, the Naval Postgraduate School's NPSat and Colorado-based Surrey Satellite Technology US's orbital test bed mission. The nTT modules will deploy conductive tapes at mission conclusion to generate electrodynamic drag and enhance aerodynamic drag to ensure deorbit well within the 25-year period required by orbital debris mitigation standards.

NASA is studying the Heliopause Electrostatic Rapid Transit System, a propellantless electrostatic tether propulsion concept, to propel spacecraft to the edge of the solar system.



The **Naval Research Laboratory** plans to launch its Tethered Electrodynamic Propulsion CubeSat Experiment (TEPCE) spacecraft through the U.S. Air Force's Satellite Test Program in late 2016. It's designed to demonstrate electrodynamic propulsion in low Earth orbit. With body-mounted solar cells, a 1-kilometer-long tape tether and tungsten-filament cathodes, TEPCE will change its orbit by 1 km a day from a nominal 300- to 860-km orbit during a one-month test. TEPCE carries GPS receivers to help characterize tether deployment and dynamics and plasma electron density sensors to provide knowledge of **Earth's plasma**.

As part of a NASA's Innovative Advanced Concepts program, Tethers Unlimited investigated the use of tethered nanosatellites to capture and de-spin asteroids and space debris to reduce the risks and costs associated with NASA's Asteroid Redirect Mission and active debris removal. Through detailed physics-based simulations, the company demonstrated that the deployment of a tether can be controlled to accomplish stable, well-behaved despin of space objects, even those with multiaxis spins, at much lower masses relative to conventional thruster-based techniques.

NASA's Marshall Space Flight Center, under a separate advanced-concepts grant, is studying a **propellantless electrostatic tether** propulsion system concept, the Heliopause Electrostatic Rapid Transit System (HERTS), for deep-space missions to outer planets, the heliopause and beyond. HERTS propels a spacecraft by employing momentum exchange from naturally occurring solar wind protons that interact with an array of positively-biased wires that extend outward 20 km from a rotating (one revolution per hour) spacecraft. In January, researchers presented results showing that HERTS can propel a scientific spacecraft to distances of 100 astronomical unit — 100 times the distance between Earth and sun — in less than 10 years.

Star Technology and Research's Electro-Dynamic Delivery Express, a spacecraft for propellantless low-Earth orbit change, has found interest from Surrey, which plans to use it as the upper stage to take its FeatherCraft-SS to sun-synchronous orbit from the space station's NanoRacks launches.

Several universities are pursuing advances in tether concepts. The University of Michigan's Miniature Tether Electrodynamics Experiment CubeSat demonstration mission was selected in February for flight through NASA's **CubeSat Launch Initiative**. The experiment will investigate the ability for a short, 10-meter-long electrodynamic tether to overcome atmospheric drag and boost femtosat-sized spacecraft, described as those weighing less than 100 grams and using less than 1 watt. U.K.'s University of Sheffield is exploring architectures for Earth–moon freight missions. North Carolina State University is exploring a concept called the Solar Wind Ion Focusing Thruster, which uses long positively-charged wires oriented in a cone shape to gather fuel from the solar wind for an ion thruster. The focused, higher-density plasma in the base of the cone is connected to an ion acceleration stage, which accelerates protons out the small end of the cone.

Rebounding from launch setbacks

by Jim Knauf

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

Despite significant space transportation accomplishments, 2015 proved again "launch is hard."

The failures of the **Russian Progress** and SpaceX Falcon cargo missions destroyed hardware bound for the International Space Station and reduced onboard reserves. The incidents — coming at the heels of the October 2014 Antares cargo mission failure — were significant, but not urgent, setbacks. Progress flights resumed in July. SpaceX has targeted late 2015 for the Falcon's next flight, pending investigation of the earlier failure.

Newly-merged Orbital ATK was anticipating a December cargo mission on an Atlas 5 and is replacing the Antares booster engines with the Russian RD-181. Japan launched its fifth H-2 Transfer Vehicle to the ISS in August.

At Cape Canaveral, Florida, Boeing built the Starliner CST-100 structural test article in a former shuttle orbiter processing facility, while United Launch Alliance built an Atlas 5 launch tower for pad access to the capsule. SpaceX completed a pad abort test of its **Crew Dragon spacecraft**. Hedging against potential commercial crew delays, NASA extended its agreement with Russia for Soyuz crew flights, of which there were four in 2015.

Amid a continuing unprecedented string of successful ULA Atlas and Delta missions, the U.S. Air Force certified Falcon 9 for national security missions and initiated studies as initial steps toward its first competitions for launches since 2006. ULA submitted to the Air Force its intent to certify its Vulcan launcher. ULA and the Air Force faced congressional pressure to end reliance on the Atlas V's Russian engine. NASA completed Falcon 9 certification for the Jason-3 science mission.

In early attempts at first stage recovery, Falcon 9 hit its target drone ship but the stages did not survive. ULA and Airbus announced plans to recover Vulcan and Ariane 6 booster engines, respectively.


NASA

Astronauts on the space station photographed the H-2 transfer vehicle on its arrival in August.

NASA and its contractors completed critical design review (CDR) and key propulsion testing for the **Block 1 Space Launch System**, and kicked off CDR for the Orion crewed spacecraft to fly atop SLS. After the December 2014 Exploration Flight Test 1 on a Delta 4 Heavy, in which Orion reentered the atmosphere at almost 9 kilometers per second, engineers closely examined the recovered spacecraft and telemetry data to improve aerophysics models for future spacecraft in this flight regime. First SLS/Orion launch is anticipated in 2018.

NASA's Launch Services Program initiated the venture-class launch services program for small science satellites and experiments, using smaller rockets than currently available.

A Russian Proton rocket suffered its sixth failure in 43 flights since December 2010, but resumed flight in August. The Proton and Progress losses and ongoing issues completing a new eastern launch site indicated continuing challenges in the Russian space industry.


Virgin Galactic

After the 2014 breakup of SpaceShipTwo, Virgin Galactic modified its second SpaceShipTwo.

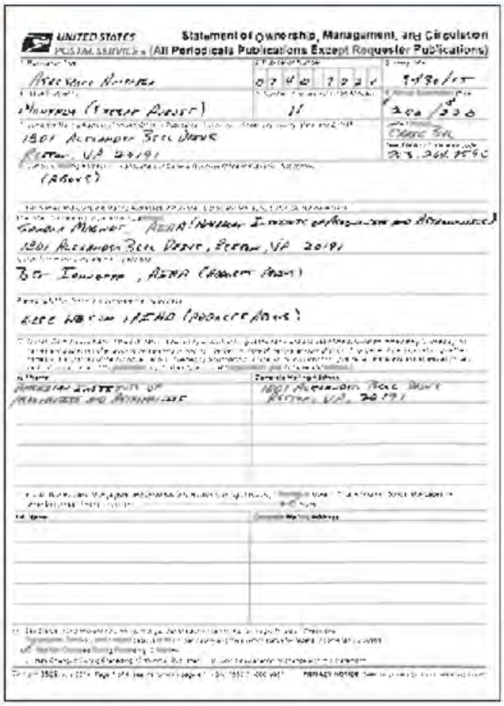
OneWeb announced the largest commercial rocket acquisition, more than 65 rockets, including Arianespace Soyuz rockets and 39 Virgin Galactic LauncherOnes. Europe approved development of Ariane 6 and its launch complex, and an upgrade to the Vega small launcher. The Airbus Safran Launchers joint venture began operations.

India's Geosynchronous Satellite Launch Vehicle completed its second consecutive successful mission with an indigenous cryogenic upper stage. China launched its new Long March 6 rocket in September.

The National Transportation Safety Board cited pilot error in the 2014 breakup of Virgin Galactic's SpaceShipTwo, but also faulted its builder, Scaled Composites, for failing to "consider and protect against the possibility that a single human error could result in a catastrophic hazard." The company modified its second SpaceShipTwo under construction in preparation for completion of flight test and start of commercial service.

Blue Origin completed its first suborbital test flight of its New Shepard launch vehicle.

Reaction Engines announced that the Air Force Research Laboratory analysis confirmed feasibility of the Synergetic Air-Breathing Rocket Engine concept to be used for the Skylon reusable space plane project.



UNITED STATES POSTAL SERVICE

Statement of Ownership, Management, and Circulation (All Periodicals Publications Except Requester Publications)

Aerospace America

0740 7722

9/30/15

Monthly (Except August)

11

1801 Alexander Bell Drive Reston, VA 20191

(Above)

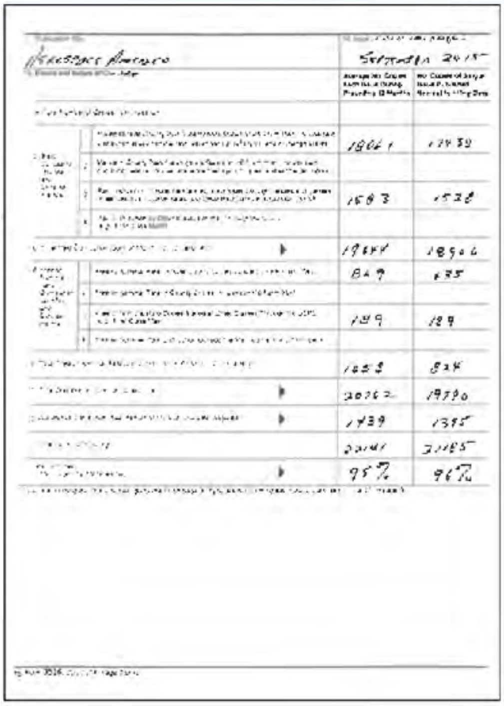
Sandra Magnus AIAA (American Institute of Aeronautics and Astronautics)

1801 Alexander Bell Drive, Reston, VA 20191

Ben Iannotta, AIAA (Address Above)

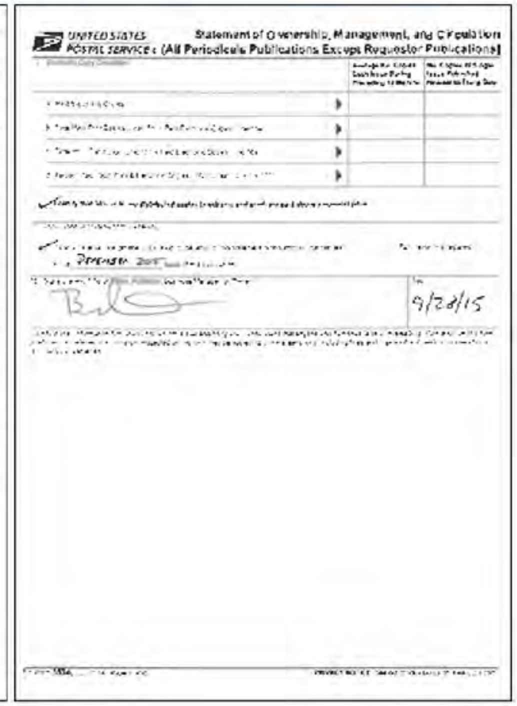
Greg Wilson AIAA (Address Above)

American Institute of Aeronautics and Astronautics — 1801 Alexander Bell Drive Reston, VA 20191



Aerospace America — September 2015

	Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
	18061	17439
	1583	1528
	19644	18906
	849	635
	189	189
	1038	824
	20702	19790
	1439	1395
	22141	21185
	95%	96%



UNITED STATES POSTAL SERVICE

Statement of Ownership, Management, and Circulation (All Periodicals Publications Except Requester Publications)

December 2015

9/28/15

25 Years Ago, December 1990

Dec. 2 Toyohiro Akiyama becomes the first Japanese to travel in space. Akiyama is a journalist for TBS, a Japanese television station that paid $12 milion to place him on Soyuz TM-11 for its trip to the Mir space station. TM-11 is flown by cosmonauts Musa Manarov and Viktor Afanasyev. Akiyama returns on TM-10 after making several broadcasts from space. NASA, Astronautics and Aeronautics 1986-1990, p. 340.

50 Years Ago, December 1965

Dec. 2 Hugh Dryden, NASA's deputy administrator who had previously served as the director of the National Advisory Committee for Aeronautics (NACA), NASA's predecessor, dies at 67 in Washington, D.C. Dryden also was a noted pioneer in aerodynamics and from 1920 headed the Aerodynamics Section of the Bureau of Standards. In 1924, he helped conduct some of the earliest studies of airfoil characteristics near the speed of sound. His main interests were in turbulence and control of the boundary layer, and in 1938 he delivered the Wright brothers lecture on these topics before the Institute of the Aeronautical Sciences. In World War II, he served on technical groups advising the armed forces on aviation matters and guided missiles. He also led the development of America's first and only guided missile successfully used in combat, the radar-homing Bat. An example may be seen at the Udvar-Hazy Center of the National Air and Space Museum. In 1947, Dryden resigned from the Bureau of Standards to become director of Aeronautical Research at NACA, then later became its director. In 1958 he was named the first deputy administrator of the newly created NASA. Aviation Week, December 6, p. 36; Washington Sunday Star, December 5, p. B2.

Dec. 3 The Soviet Union launches its 3,422-pound Luna 8 spacecraft toward the moon to soft-land there. However, the spacecraft's retro-propulsion system fires too late and the craft crashes on the moon's surface while coming in too fast. David Baker, Spaceflight and Rocketry, p. 187.

Dec. 4 The Gemini 7 spacecraft, carrying astronauts Frank Borman and James A. Lovell, Jr., is launched by a Titan 2 booster to orbit for a 14-day mission, primarily for the purpose of gathering medical data on weightlessness. It is the longest U.S. space flight to date. The crew also conducts Earth photography and radiometry experiments. Borman and Lovell perform five orbital maneuvers. They make a re-entry and recovery on December 18 after their record-breaking flight. David Baker, Spaceflight and Rocketry, p. 187.

Dec. 6 A NASA all-solid-propellant Scout vehicle launches a second 135-pound FR-1 French satellite, from Vandenberg Air Force Base, California. This satellite is designed to study the propagation of very low frequency radio waves and also to measure electron densities within the vicinity of the satellite. David Baker, Spaceflight and Rocketry, p. 187; New York Times, December 6, p. 42.

Dec. 12 Dr. W. Randolph Lovelace, the director of space medicine for NASA and a pioneer in aviation, is killed in the crash of a private twin-engine Beechcraft aircraft near Aspen, Colorado, while en route to Albuquerque, New Mexico. Back in 1940, Dr. Lovelace had shared the coveted Collier's Trophy for his role in helping to conceive the oxygen mask that became standard in World War II. In 1942, then an Army flight surgeon with the Army Medical Corps Reserve, he was also awarded the Distinguished Flying Cross for his research in high-altitude bailout procedures. In 1958, he was appointed the chairman of the NASA Special Advisory Committee on Life Science and played a key role in the selection of astronauts chosen for the coming Project Mercury missions. In April 1964, he was named the director of NASA's space medicine programs. Aviation Week, December 20, p. 188; New York Times, December 14, p. 51, and December 18, p. 16.

Dec. 15 The Gemini 6-A is launched for America's first space rendezvous mission. Piloted by Walter M. Schirra, Jr., and Thomas P. Stafford, the spacecraft succeeds in coming as close as one foot from the Gemini 7 spacecraft, and the two craft could have docked had they been equipped to do so. During the mission, the Gemini craft also fly in formation, keeping within 20 to 100 feet of each other. All four astronauts take turns in maneuvering their spacecraft. Schirra and Stafford make a precise landing on December 16. David Baker, Spaceflight and Rocketry, p. 188; New York Times, December 16, pp. 1, 28-30 and December 24, p. 1.

Past

An Aerospace Chronology
by **Frank H. Winter**
and **Robert van der Linden**

Dec. 16 NASA launches its Pioneer 6 satellite by a Thrust-Augmented Improved Delta vehicle from Cape Kennedy (now Cape Canaveral) on what is the first Earth-escape mission for the Delta rocket. The 140-pound satellite carries scientific experiments to measure solar winds, solar magnetic fields, interactions between charged particles and magnetic fields, and other phenomenon. Aviation Week, December 20, p. 26; David Baker, Spaceflight and Rocketry, p. 188.

Dec. 16 Eight aviation pioneers are added to the Aviation Hall of Fame in Dayton, Ohio. They are: Eddie Rickenbacker of World War I fame; Alexander Graham Bell for his 1890s aerodynamic lift experiments; Charles E. Taylor who built the first successful airplane engine, used by the Wright brothers in their 1903 flight; A. Roy Knabenshue, builder and flyer of steerable balloons, in 1904-1905; Thomas E. Selfridge, the first American to die while testing an experimental aircraft, in 1908 on an aircraft piloted by Orville Wright; Eugene B. Ely for his work on the first aircraft take offs and landings from carrier ships, in 1910-1911; Alfred A. Cunningham, first aviator of the Marine Corps, in 1912; and Albert C. Read, for his role in the first successful trans-Atlantic flight in 1919, commanding the Curtiss NC-4. New York Times, December 17, p. A4.

75 Years Ago, December 1940

Dec. 14 The USS Hornet is launched at Newport, Rhode Island, as the Navy's seventh aircraft carrier, joining the Saratoga, Lexington, Ranger, Yorktown, Enterprise and Wasp. The Hornet makes the Navy equal in strength in aircraft carriers to Japan. During World War II, the Hornet serves briefly, though gallantly. In April, Lt. Col. Jimmy Doolittle's Raiders are launched from its deck to attack Tokyo and other Japanese cities. In June, the ship participates in the defeat of the Japanese fleet at the Battle of Midway, and in October she is sunk during the Battle of Santa Cruz. Interavia, December 23, p. 17.

Dec. 18 Germany's radio-controlled rocket-powered Hs 293A bomb, made by the Henschel firm, makes its first flight. The Hs 293 is about 11 feet 8 inches long, has a wing span of 9 feet 6 inches, and weighs about 1,700 pounds. It is one of the few German missiles to become operational. It goes into service in August 1943, and is credited with destroying a number of Allied merchant ships and severely damaging several warships during the Italian campaign. W. Ley, Rockets, Missiles, and Space Travel, pp. 241-242.

Dec. 18 The Curtiss XSB2C-1 Helldiver makes its first flight. Helldiver is a carrier-based scout-bomber that subsequently sees service in the Pacific. Plagued by design problems and difficult to fly, the Helldiver, nevertheless eventually replaces the veteran Douglas SBD Dauntless throughout the U.S. Pacific Fleet by 1944. It has twice the bombload as its predecessor and goes on to play a decisive role on the destruction of the Imperial Japanese Navy in 1944 and 1945. Peter Bowers, Curtiss Aircraft Since 1907, pp. 424-431.

Dec. 22 Lockheed-Vega employees present a Lockheed Hudson bomber to the people of Great Britain in special ceremonies at the Union Air Terminal, Burbank, California. Immediately thereafter, the plane is flown to England by way of Canada. U.S. Air Services, February 1941, p. 29.

Dec. 29 London experiences its second great fire since the reign of Charles II when the city undergoes heavy bombing by German aircraft. The destruction includes the famous Guildhall, seven of Christopher Wren's churches, and many other buildings. St. Paul's Cathedral is saved, though at one point it is menaced by flames. Londoners spend approximately 1,180 hours under alerts in 1940 during the start of the Battle of Britain, and the sirens sounded over 400 times. Flight, January 9, p. 23.

100 Years Ago, December 1915

Dec. 12 The first all-metal full-cantilever-wing monoplane, the Junkers J-1, undergoes flight trials at Dessau, Germany. It is powered by a 120-hp Mercedes engine. Its designer, Hugo Junkers, is one of the most significant aeronautical engineers in history, having been awarded the first patent for a cantilevered wing in 1910 and also for his pioneering work in developing and promoting all-metal aircraft. Junkers also is an early advocate for flying wing designs. Eugene M. Emme, ed., Aeronautics and Astronautics 1915-60, p. 4; Francis K. Mason and Martin Windrow, Know Aviation, p. 18.

AIR FORCE INSTITUTE OF TECHNOLOGY

FACULTY POSITION
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AFB, DAYTON OH

The Department of Aeronautics and Astronautics seeks applicants for a tenure-track Aerospace Engineering faculty position (preferably at the assistant or associate professor level). The department's most urgent needs are in the following areas: Propulsion, Controls, or Aerodynamics. In addition to an earned Ph.D. in Aeronautical Engineering, Astronautical Engineering, Mechanical Engineering or a related field, the candidate should have a demonstrated or a potential ability in teaching at the graduate level and in conducting independent research for the Air Force and other government agencies. Good communication skills, both oral and written, are essential. Applicants **must** be U.S. citizens and **must** currently possess or be able to obtain/maintain a SECRET clearance. If selected, applicants must produce proof of citizenship at time of appointment. Link to full posting can be found at https://www.usajobs.gov/GetJob/ViewDetails/416590500

The Department offers both M.S. and Ph.D. degrees in Aeronautical Engineering, Astronautical Engineering, Space Systems and Materials Science. The Department has several state-of-the-art computer and experimental laboratories. Interested candidates should send a resume and the names of three references to:

Dr. Brad S. Liebst
Professor and Head
Department of Aeronautics and Astronautics
Air Force Institute of Technology
AFIT/ENY
2950 Hobson Way
Wright-Patterson AFB, OH 45433-7765
Phone: (937) 255-3069
e-mail: Bradley.Liebst@afit.edu

The Air Force Institute of Technology is an Equal Opportunity/Affirmative Action employer.

THE OHIO STATE UNIVERSITY
COLLEGE OF ENGINEERING

A Clinical Faculty Position in Aerospace Engineering

The Department of Mechanical and Aerospace Engineering at The Ohio State University invites applications from outstanding individuals for a clinical faculty position in aerospace engineering. Employment could begin as early as January 1, 2016 but applicants must be able to start by August, 2016 at the latest.

Qualifications:
Candidates with an earned doctoral degree in aerospace or mechanical engineering are preferred, however individuals with an MS degree (in aerospace or mechanical engineering) and significant aerospace work experience will also be considered. The new clinical faculty member will be expected to teach three to four undergraduate courses each semester (autumn and spring). Primary consideration will be given to those with experience and interest in teaching the following subject areas: spacecraft design, dynamics and control of aerospace vehicles, and sophomore-level Introduction to Aerospace Engineering I and II courses. Applicants with a minimum three years teaching experience are preferred, and should have a strong record of design experience and familiarity with modern design tools. Recent aerospace engineering practice is desired, specifically in the areas of spacecraft structural design and dynamics and control of aerospace vehicles. Screening of applicants will begin immediately and continue until the position is filled. Interested candidates should email a dossier including curriculum vitae, a 2-page summary of teaching philosophy and experience, and the names and addresses of four references to:

Dr. Jeffrey Bons
Chair, Clinical Faculty Search Committee
Aeroclinical2015@osu.edu (only electronic submissions please)

The Ohio State University is an affirmative/equal opportunity employer. Women, minorities, and people with disabilities are encouraged to apply and build a diverse workplace. Columbus is a thriving metropolitan community, and the University is responsive to the needs of dual career couples.

Tenure-Track Faculty Positions in Mechanical Engineering

THE UNIVERSITY OF TOLEDO 1872

The Department of Mechanical, Industrial and Manufacturing Engineering at The University of Toledo is seeking outstanding candidates for multiple tenured or tenure-track faculty positions at the Assistant or Associate Professor levels. Candidates with strong qualifications in any area of mechanical engineering will be considered, but preference will be given to candidates with research expertise in experimental thermal/fluids, mechanical design, and materials.

The department currently has 18 tenure-track or tenured faculty members and an enrollment of more than 800 undergraduate students and 90 graduate students pursuing B.S., M.S. and Ph.D. degrees. The faculty conduct funded research in excess of $4M per year across a broad range of areas. The department has a large number of experimental and computational facilities including a well instrumented subsonic wind tunnel, a small turbine engine laboratory, and flow visualization facilities. There has been a long history of collaboration with the regional automotive, energy, and glass related industries, as well as the NASA Glenn Research Center. More information about the department can be found at: http://eng.utoledo.edu/mime.

All successful candidates are expected to contribute to and play a leadership role in advancing research and teaching in their respective areas of expertise and to contribute to the diversity of the University's academic community. The University of Toledo is a comprehensive public metropolitan research university established in 1872. In addition to the College of Engineering, other professional colleges include Business Administration, Law, Medicine, Natural Sciences and Mathematics, and Pharmacy providing abundant opportunities for collaborative education and research within the University.

Applicants must have an earned doctoral degree in mechanical engineering or a related field and are expected to teach undergraduate and graduate level courses in their fields of expertise, supervise graduate student research, and develop and grow a strong, externally funded research program. Interested applicants should submit a detailed curriculum vitae, statements of research and teaching interests, and names and contact information of at least four professional references. All applicants for this position are required to complete the application online at The University of Toledo's web site: https://jobs.utoledo.edu and submit all supporting application materials, prepared in PDF format, online. Review of applications will begin December 2015 and will continue until the positions are filled.

The University of Toledo is an equal access, equal opportunity, affirmative action employer and educator

USC University of Southern California

The Department of Aerospace and Mechanical Engineering at USC is seeking applications for tenure-track or tenured faculty candidates. We seek outstanding candidates for a position at any rank. The Viterbi School of Engineering at USC is committed to increasing the diversity of its faculty and welcomes applications from women, underrepresented groups, veterans, and individuals with disabilities.

We invite applications from candidates knowledgeable in all fields of aerospace and mechanical engineering, for example in computational engineering, mechanics, thermofluids and reacting flows, robotics and autonomous systems, bio-inspired engineering, and engineering in extreme environments. Applications are also encouraged from more senior applicants whose accomplishments may be considered transformative. Outstanding senior applicants who have demonstrated academic excellence and leadership, and whose past activities document a commitment to issues involving the advancement of women in science and engineering may also be considered for the Lloyd Armstrong, Jr. Endowed Chair, which is supported by the Women in Science and Engineering (WiSE) Program endowment.

Applicants must have earned a Ph.D. or the equivalent in a relevant field by the beginning of the appointment and have a strong research and publication record. Applications must include a letter clearly indicating area(s) of specialization, a detailed curriculum vitae, a concise statement of current and future research directions, a teaching statement, and contact information for at least four professional references. This material should be submitted electronically at http://ame-www.usc.edu/facultypositions/. Applications should be submitted by January 4, 2016; any received after this date may not be considered.

USC Viterbi
School of Engineering

USC is an equal-opportunity educator and employer, proudly pluralistic and firmly committed to providing equal opportunity for outstanding persons of every race, gender, creed and background. The University particularly encourages members of underrepresented groups, veterans and individuals with disabilities to apply.

UNIVERSITY OF NOTRE DAME

The Department of Aerospace & Mechanical Engineering at the University of Notre Dame is seeking outstanding candidates to fill three open faculty positions in the area of Experimental Fluid Dynamics. Of particular interest are candidates that will both complement and expand selected signature research areas within the Notre Dame Institute for Flow Physics and Control (FlowPAC). These areas include Turbo-machinery, Environmental Fluid Dynamics, High-speed Reacting Flows and Combustion, and Unsteady Aerodynamics and Aero-acoustics. Applicants at both the Assistant and Associate Professor rank are sought. Exceptionally qualified individuals at the rank of Full Professor may also be considered. Candidates must hold an earned doctorate in an appropriate field and are expected to establish an externally funded research program as well as contribute fully to both undergraduate and graduate instruction. Salary and rank will be commensurate with qualifications and experience.

The University of Notre Dame is a US News and World Report top-20 national research university that

offers a unique opportunity for professional growth in an environment that values scholarship, education and community. Current research at Notre Dame has a strong emphasis on interdisciplinary science that bridges traditional groups and even departmental boundaries, with clear ties to significant aerospace or mechanical applications. Notre Dame is dedicated to becoming a leading research university and is investing millions of dollars in state-of-the-art facilities, including the new Stinson-Remick Engineering building and the Center for Research Computing. The city of South Bend and surrounding counties have a vibrant and diverse economy, excellent school systems, and close proximity to Chicago and Lake Michigan.

Further information about the University and the Department can be found at: http://www.nd.edu/~ame/.

Interested persons should apply online at http:// apply.interfolio.com/32430. For full consideration, applications should be received by December 20, 2015.

The University of Notre Dame seeks to attract, develop, and retain the highest quality faculty, staff and administration. The University is an Equal Opportunity Employer, and is committed to building a culturally diverse workplace. We strongly encourage applications from female and minority candidates and those candidates attracted to a university with a Catholic identity. Moreover, Notre Dame prohibits discrimination against veterans or disabled qualified individuals, and requires affirmative action by covered contractors to employ and advance veterans and qualified individuals with disabilities in compliance with 41 CFR 60-741.5(a) and 41 CFR 60-300.5(a).

JAMES WORTH

BAGLEY

COLLEGE OF ENGINEERING

MISSISSIPPI STATE UNIVERSITY

Head and Endowed Chair

Department of Aerospace Engineering

The Bagley College of Engineering at Mississippi State University (MSU) is seeking candidates for the Head of the Department of Aerospace Engineering (ASE). The ASE Head also holds the Bill and Carolyn Cobb Endowed Chair. The primary aim of the Department Head of Aerospace Engineering is to advance the national stature of the department. The Department Head is under the administrative supervision of the Dean of the Bagley College of Engineering and is responsible for the overall administration of the department. The successful candidate must possess an earned doctorate in aerospace engineering or a closely related field, must have earned national recognition by a distinguished record of accomplishments in aerospace engineering education and research, and must qualify for the rank of professor. In addition, a baccalaureate degree in engineering is desirable.

The Department of Aerospace Engineering is one of eight academic departments in the Bagley College of Engineering. The department offers an ABET-accredited undergraduate program in aerospace engineering, as well as graduate studies leading to MS and PhD degrees. The department is composed of approximately 273 undergraduate and 62 graduate students, 13 tenured/tenure-track faculty members, 6 instructors, and 3 staff members. Faculty includes a member of the National Academy of Engineering and 13 faculty that are Fellows and/or Associate Fellows of national technical organizations. Faculty members have developed strong research programs in materials and structures, fluid dynamics, computational simulations & design, and unmanned aerial systems and play a vital role in several college and university research centers such as the Raspet Flight Research Laboratory (http://www.raspet.msstate.edu/), the FAA's Center of Excellence for UAS Research (http://www.assureuas.org/), the High Performance Computing Collaboratory (http://www.hpc.msstate.edu/), the Center for Advanced Vehicular Systems (http://www.cavs.msstate.edu/), and a new Advanced Composites Institute. The undergraduate program offers concentrations in aeronautics and astronautics. The department actively engages students in research, as well as extracurricular experiences such as the Association for Unmanned Vehicle Systems International Student UAS Competition, at which they placed first in 2008 and second in 2010. The "Space Cowboys" Rocket Design Team won the 2015 Intercollegiate Rocket and Engineering Competition which included over 50 teams from 7 nations and regularly receives the AIAA Community Outreach Award.

MSU (www.msstate.edu), a Carnegie Foundation Very High Research University, is a comprehensive public institution with more than 20,000 graduate and undergraduate students and approximately 1,300 full-time faculty members, located in Starkville, Mississippi (visit.starkville.org). The Bagley College of Engineering, with over 100 tenure-track/tenured faculty members, has an approximate enrollment of 3,450 undergraduate and 625 graduate students. It ranks 73rd nationally in research expenditures with 3 programs in the top 50.

The position is available beginning July 1, 2016, but the starting date is negotiable. The screening of candidates will begin January 4, 2016 and will continue until the position is filled. Applications must be submitted online at www.jobs.msstate.edu for PARF #9351. Applicants should submit a curriculum vitae, names and contact information for at least three professional references, and a statement (limited to three pages) that describes their vision for the department. Candidates must also complete the on-line Personal Data Information Form. Nominations or questions should be directed to Dr. Roger L. King, Search Committee Chair, Mississippi State University, Email: rking@cavs.msstate.edu, Phone: (662) 325-2189.

MSU is an equal opportunity employer, and all qualified applicants will receive consideration for employment without regard to race, color, religion, ethnicity, sex (including pregnancy and gender identity), national origin, disability status, age, sexual orientation, genetic information, protected veteran status, or any other characteristic protected by law. We always welcome nominations and applications from women, members of any minority group, and others who share our passion for building a diverse community that reflects the diversity in our student population.

Embry Riddle Aeronautical University, Daytona Beach
Department of Aerospace Engineering Faculty Position

The Department of Aerospace Engineering at Embry-Riddle Aeronautical University in Daytona Beach, Florida has an ambitious agenda for the next five years focused on expanding graduate programs, research capabilities, facilities, and recruiting highly talented faculty. An exciting plan for a new state-of-the-art engineering building housing research laboratories including a new wind tunnel and supporting facilities has been approved and will be completed by spring of 2017 in support of this agenda.

The Department invites applications for a faculty position at the Assistant or Associate Professor rank, although an appointment at the Professor level may be considered. Successful candidates for the Assistant Professor rank should demonstrate a potential to establish and grow a strong research program and to excel at teaching and mentoring undergraduate and graduate students. Applicants for the Associate rank should have an exemplary record of teaching and scholarly activities including externally funded research. Appointment at the Professor rank may be considered for individuals with exceptional qualifications and national recognition. We intend to fill the position starting in August 2016. The preferred area of expertise is Dynamics and Control, with specialization in Astronautics and Space Applications. However, applicants in all areas of Aerospace Engineering will be considered.

An earned doctorate in Aerospace Engineering or a closely related field is required. Applicants must submit a cover letter, a curriculum vitae, a detailed research and teaching plan, and the names of at least three references to the ERAU web site http://eraucareers.erau.edu, or to:

AE Faculty Search
c/o Human Resources
Embry-Riddle Aeronautical University
600 S. Clyde Morris Blvd., Daytona Beach, FL 32114

AUBURN UNIVERSITY
SAMUEL GINN COLLEGE OF ENGINEERING
AEROSPACE

The Department of Aerospace Engineering at Auburn University invites applications for multiple tenure track faculty positions at the assistant or associate professor rank. Exceptional candidates may be considered for the prestigious **Walt and Virginia Woltosz Professorship**. Applicants with expertise in all areas related to aerospace engineering are invited to apply. Applicants must have an earned doctorate in aerospace engineering, mechanical engineering, or a closely related field. They will be expected to fully contribute to the department's mission and the development of a strong, nationally recognized, funded research program.

Applicants can login and submit a cover letter, CV, research vision, teaching philosophy, and three references at: http://aufacultypositions.peopleadmin.com/postings/1247

Cover letters may be addressed to: Dr. Joseph Majdalani, Faculty Search Committee Chair, 211 Davis Hall, Auburn, AL 36849. The applicant review process will begin December 14, 2015 and continue until successful candidates are identified. Candidates may continue to apply until the search has ended. The candidates selected for these positions must be able to meet eligibility requirements to work in the U.S. at the time of appointment and continue working legally for the proposed term of employment. Excellent communication skills are required. Additional information may be found at: http://www.eng.auburn.edu/aero/

Auburn University is an EEO/Vet/Disability employer.

AIAA Bulletin

The AIAA Tucson Section's Kid Club, which combines STEM Plus Art (STEAM), has offered sessions ranging from aviation, optics, planetary science, rocketry, and systems engineering. See more information about the AIAA Tucson Section STEM endeavors on page **B11**.

DECEMBER 2015

AIAA Directory

AIAA HEADQUARTERS
12700 Sunrise Valley Drive, Suite 200
Reston, VA 20191-5807
www.aiaa.org

To join AIAA; to submit address changes, member inquiries, or renewals; to request journal fulfillment; or to register for an AIAA conference.
Customer Service: 800/639-AIAA†

Other Important Numbers: ***Aerospace America*** / Greg Wilson, ext. **7596** • ***AIAA Bulletin*** / Christine Williams, ext. **7575** • **AIAA Foundation** / Karen Thomas, ext. **7520** • **Book Sales** / **800.682.AIAA** or **703.661.1595**, Dept. 415 • **Communications** / John Blacksten, ext. **7532** • **Continuing Education** / Megan Scheidt, ext. **7511** • **Corporate Members** / Tobey Jackson, ext. **7570** • **Editorial, Books and Journals** / Heather Brennan, ext. **7568** • **Exhibits and Sponsorship** / Tobey Jackson, ext. **7570** • **Honors and Awards** / Carol Stewart, ext. **7538** • **International Affairs** / Betty Guillie, ext. **7573**; Emily Springer, ext. **7533** • **Journal Subscriptions, Member** / **800.639.AIAA** • **Journal Subscriptions, Institutional / Online Archive Subscriptions** / Michele Dominiak, ext. **7531** • **Media Relations** / Duane Hyland, ext. **7558** • **Public Policy** / Steve Sidorek, ext. **7541** • **Section Activities** / Chris Jessee, ext. **7517** • **Standards, Domestic** / Hilary Woehrle, ext. **7546** • **Standards, International** / Nick Tongson, ext. **7515** • **Student Programs** / Rachel Dowdy, ext. **7577** • **Technical Committees** / Betty Guillie, ext. **7573**

† U.S. only. International callers should use 703/264-7500.

All AIAA staff can be reached by email. Use the formula first name last initial@aiaa.org. Example: megans@aiaa.org.

Addresses for Technical Committees and Section Chairs can be found on the AIAA Web site at **http://www.aiaa.org**.

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

Event & Course Schedule

DATE	MEETING (Issue of *AIAA Bulletin* in which program appears)	LOCATION	ABSTRACT DEADLINE
2016			
2–3 Jan	2nd AIAA CFD Aeroelastic Prediction Workshop	San Diego, CA	
2–3 Jan	Guidance of Unmanned Aerial Vehicles	San Diego, CA	
2–3 Jan	Systems Requirements Engineering	San Diego, CA	
3 Jan	Structural Dynamics of Rocket Engines Tutorial	San Diego, CA	
4 Jan	AIAA Associate Fellows Recognition Ceremony and Dinner	San Diego, CA	
4–8 Jan	AIAA SciTech 2016 (AIAA Science and Technology Forum and Exposition) **Featuring:** 24th AIAA/AHS Adaptive Structures Conference; 54th AIAA Aerospace Sciences Meeting; AIAA Atmospheric Flight Mechanics Conference; 15th Dynamics Specialists Conference; AIAA Guidance, Navigation, and Control Conference; AIAA Information Systems—Infotech@Aerospace Conference; AIAA Modeling and Simulation Technologies Conference; 18th AIAA Non-Deterministic Approaches Conference; 57th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference; 9th Symposium on Space Resource Utilization; 3rd AIAA Spacecraft Structures Conference; 34th Wind Energy Symposium	San Diego, CA	**2 Jun 15**
25-28 Jan†	Annual Reliability and Maintainability Symposium (RAMS)	Tucson, AZ (Contact: Sean Carter, seancarter67@gmail.com, www.rams.org)	
Feb–Jun	Introduction to Computational Fluid Dynamics	Home study course	
Feb–Jun	Advanced Computational Fluid Dynamics	Home study course	
Feb–Jun	Computational Fluid Turbulence	Home study course	
Feb–Jun	Spacecraft Design and Systems Engineering	Home study course	
14–18 Feb†	26th AAS/AIAA Space Flight Mechanics Meeting	Napa, CA (Contact: Ryan Russell, 512.471.4190, ryan.russell@utexas.edu, www.space-flight.org/docs/2016_winter/2016_winter.html)	
8–10 Mar	AIAA DEFENSE 2016 (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	**8 Oct 15**
5–12 Mar†	2016 IEEE Aerospace Conference	Big Sky, MT (Contact: Erik Nilsen, 818.354.4441, Erik.n.nilsen@jpl.nasa.gov, www.aeroconf.org)	
16 Mar	AIAA Congressional Visits Day	Washington, DC	
19–21 Apr†	16th Integrated Communications and Surveillance (ICNS) Conference	Herndon, VA (Contact: Denise Ponchak, 216.433.3465, denise.s.ponchak@nasa.gov, http://i-cns.org)	
5 May	Aerospace Today ... and Tomorrow—An Executive Symposium	Williamsburg, VA	
16–20 May†	SpaceOps 2016: 14th International Conference on Space Operations	Daejeon, Korea	**30 Jul 15**
30 May–1 Jun†	22nd AIAA/CEAS Aeroacoustics Conference	Lyon, France	**9 Nov 15**
30 May–1 Jun†	23rd Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (Contact: Ms. M. V. Grishina, +7 812 499 8181, icins@eprib.ru, www.elektropribor.spb.ru)	
13–17 Jun	AIAA AVIATION 2016 (AIAA Aviation and Aeronautics Forum and Exposition) **Featuring:** 32nd AIAA Aerodynamic Measurement Technology and Ground Testing Conference; 34th AIAA Applied Aerodynamics Conference; AIAA Atmospheric Flight Mechanics Conference; 8th AIAA Atmospheric and Space Environments Conference	Washington, DC	**5 Nov 15**

DATE	MEETING (Issue of *AIAA Bulletin* in which program appears)	LOCATION	ABSTRACT DEADLINE
	16th AIAA Aviation Technology, Integration, and Operations Conference AIAA Flight Testing Conference 8th AIAA Flow Control Conference 46th AIAA Fluid Dynamics Conference 17th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference AIAA Modeling and Simulation Technologies Conference 47th AIAA Plasmadynamics and Lasers Conference 46th AIAA Thermophysics Conference		
15 Jun	Aerospace Spotlight Awards Gala	Washington, DC	
16–17 Jun	6th AIAA CFD Drag Prediction Workshop	Washington, DC	
5–8 Jul†	ICNPAA 2016 Mathematical Problems in Engineering, Aerospace and Sciences	University of La Rochelle, France (Contact: Prof. Seenith Sivasundaram, 386.761.9829, seenithi@gmail.com, www.icnpaa.com)	
25–27 Jul	AIAA Propulsion and Energy 2016 (AIAA Propulsion and Energy Forum and Exposition) Featuring: 52nd AIAA/SAE/ASEE Joint Propulsion Conference 14th International Energy Conversion Engineering Conference	Salt Lake City, UT	12 Jan 16
13–16 Sep	AIAA SPACE 2016 (AIAA Space and Astronautics Forum and Exposition) Featuring: AIAA SPACE Conference AIAA/AAS Astrodynamics Specialist Conference AIAA Complex Aerospace Systems Exchange	Long Beach, CA	
25–30 Sept†	30th Congress of the International Council of the Aeronautical Sciences (ICAS 2016)	Daejeon, South Korea (Contact: www.icas.org)	15 Jul 15
25–30 Sept†	35th Digital Avionics Systems Conference	Sacramento, CA (Contact: Denise Ponchak, 216.433.3465, denise.s.ponchak@nasa.gov, www.dasconline.org)	
26–30 Sept†	67th International Astronautical Congress	Guadalajara, Mexico (Contact: http://www.iafastro.org/guadalajara-to-host-iac-2016)	
17–20 Oct†	22nd KA and Broadband Communications Conference and the 34th AIAA International Communications Satellite Systems Conference	Cleveland, OH (Contact: Chuck Cynamon, 301.820.0002, chuck.cynamon@gmail.com)	
2017			
9–13 Jan	AIAA SciTech 2017 (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	

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

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

AIAA Continuing Education courses.

From the Corner Office

ADAPT, EVOLVE, AND SUCCEED

Jim Maser, AIAA President-Elect

I am privileged and honored to be the next President of AIAA, and as I prepare to take on this role, I am looking forward to serving during such a dynamic time in the aerospace industry. As the business continues to evolve in diverse ways each year, posing new opportunities and challenges, we must be able to adapt in order to remain relevant.

With the rebound of the world's economies coupled with the rise of emerging markets, commercial aviation is experiencing an unprecedented boom. Airlines are ordering record numbers of aircraft, with Indigo Airlines topping the list at 250 aircraft in a single order. Boeing and Airbus together have more than 10,000 aircraft on order alone. Suppliers such as engine makers are therefore facing some of the largest production ramp ups in history. New engine technologies are revolutionizing the industry, enhancing efficiencies in fuel burn, maintenance, and environmental impact. It is no surprise that global airline revenues are projected to reach a record $29.3 billion this year.

New international actors have the potential to be players as the Russian Irkut MC-21, the Chinese COMAC C919, and the Bombardier CSeries aircraft enter the market in the next couple of years. It will be interesting to see the global airline industry's reaction to these products and how their success or failure will affect this segment of the market.

As commercial aviation expands to new heights, the defense industry is facing a more constrained environment. Military budgets are under constant scrutiny by the government, driving the demand for more information and the requirement for greater affordability. This financial pressure restricts opportunities to compete for research and development (R&D) contracts, resulting in less overall platforms. Long-term strategic planning to determine allocation of scarce budget money is key to operating in this current environment. This poses a significant challenge in the face of the world's growing military powers such as China. Their defense investment is estimated to be around 30 percent of the world's military spending and is projected to continue to increase.

Facing limited and uncertain government funding, the U.S. space industry has been experiencing a proliferation of commercial actors. Much like commercial aviation, which moved toward independent R&D after initial federal government leadership in the early days, the space industry is moving away from a solely government-led R&D infrastructure to become more self-sufficient. This development allows NASA to transfer some responsibilities to this growing segment of the industry and plan for more targeted, strategic, and ambitious missions and research. This move is even more important when considering the roles of China and Russia as influential international players in the future. China is estimated to grow its investment at a rate of 10 percent per year. On the other hand, the Russian space program has been experiencing delays and launch failures—leading experts to say their industry could be in decline.

The opportunities and challenges in the ongoing trends in the commercial aviation, defense, and space segments demonstrate the need for us to examine our own AIAA organization to move successfully with the industry. We are already taking action by evaluating the structure of our governance, which will allow us to be not only more flexible, but also relevant to the aerospace community writ large. To evaluate what it means to be "relevant" today, AIAA's Institute Development Committee is establishing a dedicated "Study Group" to determine who our customers are—and should be—and what it means to be relevant, and valuable, to those different customers and market segments. Another area of consideration is how should we measure success? What are the metrics we put in place so we know if we are "moving the needle" toward true relevance and effectiveness? Most importantly, we must build these fundamentals upon a foundation of agility. To be flexible is to be successful in this industry. We will regularly take the pulse of members and nonmembers alike to drive these changes.

Thank you again for allowing me to serve the Institute during such a significant time. I look forward to working with you.

Registration Now Open for Congressional Visits Day

Make a difference in the future of aerospace at AIAA Congressional Visits Day (CVD; **http://www.aiaa.org/CVD**) on 16 March 2016. This event brings together passionate aerospace professionals and students in Washington, D.C., for a day of advocacy and awareness with lawmakers. Join us and let your voice be heard by your state's congressional delegation and staff on key policy issues that matter most. To register, go to **http://www.aiaa.org/CVD2016**.

AIAA TO RECOGNIZE CLASS OF 2016 ASSOCIATE FELLOWS IN JANUARY

AIAA formally will honor and induct the Class of 2016 Associate Fellows at its AIAA Associate Fellows Recognition Ceremony and Dinner on Monday, January 4, 2016, at the Manchester Grand Hyatt, San Diego, California, in conjunction with the AIAA Science and Technology Forum and Exposition 2016 (AIAA SciTech 2016), 4–8 January 2016.

"I sincerely congratulate the Class of 2016 Associate Fellows," said AIAA President Jim Albaugh. "Each of these individuals has shown extraordinary commitment to furthering the advancement of science and technology in the aerospace community, and I look forward to helping to celebrate their achievements this January in San Diego. AIAA thanks them for their efforts, and we are excited to see the ongoing results of their continued efforts to shape the future of aerospace."

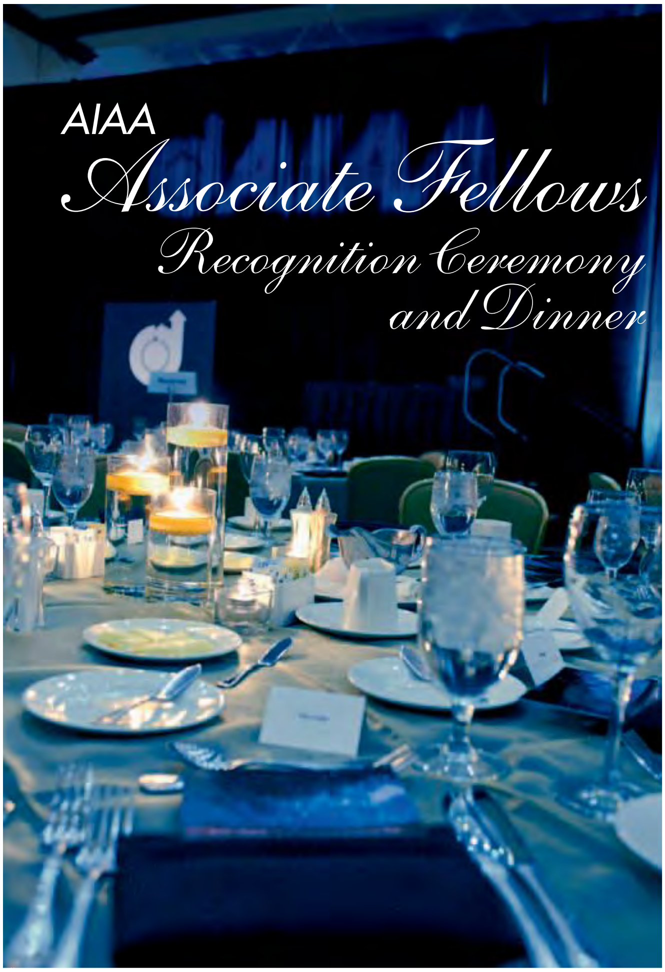
The grade of Associate Fellow recognizes individuals "who have accomplished or been in charge of important engineering or scientific work, or who have done original work of outstanding merit, or who have otherwise made outstanding contributions to the arts, sciences, or technology of aeronautics or astronautics." To be selected as an Associate Fellow an individual must be an AIAA Senior Member in good standing, with at least twelve years professional experience, and be recommended by a minimum of three current Associate Fellows.

The Class of 2016 Associate Fellows are:

Daniel Alazard, ISAE-SUPAERO
Michael Anderson, U.S. Air Force Academy
Leandro Barajas, Dynetics, Inc.
David Beale, Aerospace Testing Alliance
David Bearden, The Aerospace Corporation
Kamran Behdinan, University of Toronto
Jeff Bingham, United States Senate Commerce, Science and Transportation Committee Staff (retired)
Eric Blades, ATA Engineering, Inc.
Robert Breidenthal, University of Washington
Andrew Brown, NASA Marshall Space Flight Center
Daniel Brown, Air Force Research Laboratory
Philip Burkholder, Rolls-Royce Corporation
Steven Bussolari, U.S. Air Force
Michael Butler, Johns Hopkins University/Applied Physics Laboratory
Samuel Butler, The Boeing Company
Jason Cassibry, University of Alabama in Huntsville
Haixin Chen, Tsinghua University
Peter Chen, Intelligent Automation Inc.
Sergey Chernyshev, TsAGI
Kimberley Clayfield, CSIRO
Stephen Cook, The MITRE Corporation
Craig Cooning, The Boeing Company
Victoria Cox, Veracity Engineering
Agamemnon Crassidis, Rochester Institute of Technology
Brian Danowsky, Systems Technology, Inc.
Andrew Dawdy, The Aerospace Corporation
Michael Deitchman, Department of the Navy (SES Retired)
Edward DiGirolamo, Lockheed Martin Corporation
Kenneth Dorsett, Lockheed Martin Corporation
John Doty, University of Dayton
David Driver, NASA Ames Research Center
Daniel Dumbacher, Purdue University
David Eccles, The Aerospace Corporation
"J.R" Reginald Edwards, Lockheed Martin Corporation
William Emrich, NASA Marshall Space Flight Center
Daniel Erwin, University of Southern California
Thomas Fanciullo, Aerojet Rocketdyne
Hector Fenech, Eutelsat SA
Lawrence Fink, The Boeing Company
Roger Franzen, Australian National University
Susan Frost, NASA Ames Research Center
Gregory Gatlin, NASA Langley Research Center
Thomas Giel, ERC/Jacobs ESSSA Team, Marshall Space Flight Center
Anouck Girard, University of Michigan
James Gregory, The Ohio State University
Norman Wayne Hale, Special Aerospace Services, LLP
David Hall, DHC Engineering
Neil Hall, Lockheed Martin Corporation
Tucker Hamilton, U.S. Air Force
Jae-Hung Han, Korea Advanced Institute of Science and Technology
Thomas Hancock, SAIC
Shahab Hasan, LMI
Darin Haudrich, The Boeing Company
James Heidmann, NASA Glenn Research Center
Gregory Hiemenz, InnoVital Systems, Inc.
George Hindman, Keystone Aerospace
Keith Hollingsworth, University of Alabama in Huntsville
John R "Rick" Hooker, Lockheed Martin Corporation
Michael Houts, NASA Marshall Space Flight Center
Patricia Hynes, New Mexico State University
Dana Keoki Jackson, Lockheed Martin Corporation
Zonglin Jiang, Institute of Mechanics, Chinese Academy of Sciences
Michael Johnson, NASA Kennedy Space Center
Anya Jones, University of Maryland
John Karas, Lockheed Martin Corporation
Shawn Keshmiri, University of Kansas
Sergey Kravchenko, The Boeing Company
Miroslav Krstic, University of California, San Diego
Ira Kuhn, Directed Technologies Inc.
Philippe Lavoie, University of Toronto
Phillip Ligrani, University of Alabama in Huntsville
Chao-An Lin, National Tsing Hua University
Tianshu Liu, Western Michigan University
Andrew Lovejoy, NASA Langley Research Center
Byron Lowry, Lockheed Martin Corporation
Haoxiang Luo, Vanderbilt University
Luca Maddalena, University of Texas at Arlington
Balasubramanyam Madhanabharatam, Consultant
Brant Maines, Lockheed Martin Corporation
Faure Joel Malo-Molina, Raytheon
Arif Masud, University of Illinois
Jehanzeb Masud, Air University
Ralf Mayer, The MITRE Corporation
Craig McLaughlin, University of Kansas
Jack McNamara, The Ohio State University
Pamela Melroy, Defense Advanced Research Projects Agency
Richard Miller, Clemson University
Marc Millis, Tau Zero Foundation
Kristi Morgansen, University of Washington
John Mulholland, The Boeing Company
James Nabity, University of Colorado
Eliahu Niewood, MIT Lincoln Laboratory
Hiroaki Nishikawa, National Institute of Aerospace
Donald Nixon, Moog, Inc.
Scott Norwood, Lockheed Martin Corporation
Allison O'Connor, Moog, Inc.
Dennis O'Donoghue, The Boeing Company
Gregory Olsen, Mississippi State University
Irewole Orisamolu, Pratt & Whitney
Eric Paterson, Virginia Polytechnic Institute and State University
Jeremy Pinier, NASA Langley Research Center
Marcia Politovich, National Center for Atmospheric Research

Alexander Povitsky, University of Akron
Gregory Power, Aerospace Testing Alliance
Adam Przekop, NASA Langley Research Center
Michael Raftery, The Boeing Company (retired)
Venkatramanan Raman, University of Michigan
Wayne Rast, Texas Space Alliance
Aloysius Reisz, Reisz Engineers
Darrell Ridgely, Raytheon
Gary Roberge, Pratt & Whitney
Luke Roberson, NASA Kennedy Space Center
Shann Julie Rufer, NASA Langley Research Center
William Schneider, Lockheed Martin Corporation
Gregory Scott, Naval Research Laboratory
Jürgen Seidel, U.S. Air Force Academy
Alex Selvarathinam, Lockheed Martin Corporation
Prasenjit Sengupta, Optimal Synthesis Inc.
Scott Seymour, Aerojet Rocketdyne
Joseph Sheeley, Aerospace Testing Alliance
Zach Sherman, Lockheed Martin Corporation
Jaiwon Shin, NASA Headquarters
Gopalakrishnan Srinivasan, Indian Institute of Science
Uri Shumlak, University of Washington
Michael Sievers, Jet Propulsion Laboratory
Christopher Singer, NASA Marshall Space Flight Center
Puneet Singla, University at Buffalo—The State University of New York
Carolyn Slivinski, Space Telescope Science Institute
Michael Smart, The University of Queensland
Thomas Smith, The Boeing Company
Jack Sokhey, Rolls-Royce Corporation
Jared Squire, Ad Astra Rocket Company
Thomas Starchville, The Aerospace Corporation
Scott Starin, NASA Goddard Space Flight Center
Ephraim Suhir, Portland State University/ERS Company
Brian Thurow, Auburn University
Charles Tinney, University of Texas at Austin
Lawrence Townsend, University of Tennessee
Robert Tramel, Kord Technologies Inc.
Colin Tucker, U.S. Air Force
Bruce Underwood, NASA Goddard Space Flight Center
Wayne Van Lerberghe, The Aerospace Corporation
Ian Walker, Clemson University
Xiaowen Wang, Air Force Research Laboratory
Frank Wazzan, University of California, Los Angeles
Julien Weiss, École de Technologie Supérieure
Thomas Wendel, The Boeing Company
Bruce Willis, Jacobs Technology, Inc.
Michael Woronowicz, Stinger Ghaffarian Technologies, Inc.
Jong-Shinn Wu, National Chiao Tung University
Patrick Yee, The Aerospace Corporation
Renato Zanetti, NASA Johnson Space Center
John Joseph Zipay, NASA Johnson Space Center

For more information on the AIAA Associate Fellows Program, please contact Patricia A. Carr at triciac@aiaa.org or 703.264.7523.



Celebrating the Class of 2016

Each year, the Institute recognizes exemplary professionals for their accomplishments in engineering or scientific work, outstanding merit and contributions to the art, science, or technology of aeronautics or astronautics.

The Class of 2016 Associate Fellows will be officially recognized during the Associate Fellows Recognition Ceremony and Dinner, to be held in conjunction with **AIAA SciTech 2016** on Monday evening, 4 January 2016, at the Manchester Grand Hyatt in San Diego, California.

For a complete listing of the Class of 2016 Associate Fellows, please visit **www.aiaa.org/2016AssociateFellows/**

Please support your colleagues, and join us for the induction of the 2016 Associate Fellows. Tickets to this celebrated event are available on a first-come, first-served basis and can be purchased for $100 via the AIAA SciTech 2016 registration form, 2016 Associate Fellows Dinner event registration form, or onsite (based on availability).

Business attire/semi-formal attire is requested. For more information, please contact **Patricia A. Carr,** Program Manager, Membership Advancement Program, at **triciac@aiaa.org** or **703.264.7523.** On the web, please visit **www.aiaa-SciTech.org/Recognition.**

AIAA
Shaping the Future of Aerospace

15-888

FREITAG AWARD GIVEN IN SEPTEMBER

On 14 September 2015, **Carsten Spooner** was presented with the AIAA Joseph Freitag, Sr. Award at the Daimler Training School in Stuttgart, Germany. Spooner completed his apprenticeship preparing him to take a technician position in any part of the Daimler automobile manufacturing process. He was selected for the award by the school's faculty because he had completed his studies a year early, had high grades, exhibited social and leadership qualities, and has been accepted to the University of Stuttgart to pursue a Bachelor Degree in Mechanical Engineering.

In addition to his academic achievements Mr. Spooner was noted for his outside interests in marathon running, cross country bicycle competitions, restoring cars and equipment, piano playing, and volunteering sailing lessons and organizing events for younger people. and contributing to his community. Upon completion of his studies, he intends to apply for a position at Daimler in the Research and Development field.

Michael Lachnit, who was the third person to receive this award, presented Mr. Spooner with this year's award. Mr. Lachnit completed his Bachelor of Mechanical Engineering and is now employed by Daimler, setting up production lines in other countries that provide sub-assemblies to Daimler. He spoke about the inspiration he got from the life of Joseph Freitag Sr., who graduated from the Daimler School in 1922 and became a noted designer for the Sperry Gyroscope Company. Mr. Freitag Sr. lived to 102, and attributed his success to the best thing he got from Germany – the Daimler education. The Freitag Award was established by his family and friends and managed by AIAA.

Mr. Spooner, left, receives the certificate and award check from Mr. Lachnit.

CALL FOR PAPERS FOR *JOURNAL OF GUIDANCE, CONTROL, AND DYNAMICS*

Special Issue on Space Domain Awareness

The *Journal of Guidance, Control, and Dynamics* (*JGCD*) is devoted to the advancement of the science and technology of guidance, control, and dynamics through the dissemination of original archival papers disclosing significant technical knowledge, exploratory developments, design criteria, and applications in aeronautics, astronautics, celestial mechanics, and related fields. The journal publishes qualified papers on dynamics, stability, guidance, control, navigation, optimization, electronics, avionics, and information processing related to aeronautical, astronautical, and marine systems.

Space Domain Awareness (SDA) is the actionable knowledge required to predict, avoid, deter, operate through, recover from, and/or attribute cause to the loss and/or degradation of space capabilities and services. The only purpose for SDA is to provide decision-making processes with a quantifiable and timely body of evidence of behavior(s) attributable to specific space threats and/or hazards. SDA encompasses all activities of information tasking, collection, fusion, exploitation, quantification, and extraction to end in credible threat and hazard identification and prediction. Understanding the synergy between the space environment, the interaction of this space environment with objects (astrodynamics), the effects of this space environment on objects (operational and not), and the available sensors and sources of information are critical to meaningful SDA. Included in the SDA purview is collecting raw observables, identifying physical states and parameters (e.g., orbit, attitude, size, shape), determining functional characteristics (e.g., active vs passive, thrust capacity, payloads), inferring mission objectives (e.g., communications, weather), identifying behaviors, and predicting specific credible threats and hazards. Intuitively, SDA is a natural "big data" problem, drawing from a surfeit of existing and potential metadata and data sources. The problem at hand is 1) how these articulated needs can be rigorously addressed using first-principles, 2) what methods, techniques, and technologies must be leveraged from other fields or targeted for development, and 3) what sensors, phenomenology, sensor tasking, or additional data are needed to support the SDA mission.

Existing research and technology focus largely on collecting observables, identification of physical states and parameters, and determining functional characteristics. Selected examples include extracting observations and new information from non-traditional sensors, improving track association and initiation using admissible regions, using finite set statistics methods to improve detection and tracking, and classifying space objects using ontology and taxonomy approaches. Substantial recent progress on these topics has been presented at the AIAA/AAS Spaceflight Mechanics Meetings and AIAA/AAS Astrodynamics Specialist Conferences over the past decade.

The special issue on SDA will consolidate the latest results and key accomplishments of research performed to date in addressing this important and difficult problem, and will include the following topics:

- Fundamental theoretical results that directly support SDA efforts
- Novel application of methods, techniques, or technologies from other fields to the SDA problem
- Investigation of wholly new methods to achieve desired SDA outcomes

More information about this special issue as well as guidelines for preparing your manuscript can be found in the full Call for Papers on the journal website in Aerospace Research Central (**http://arc.aiaa.org/loi/jgcd**).

Deadline: Submissions are due by **15 May 2016**, with prior approval of the Guest Editor
Contact Email: Ping Lu, Editor-in-Chief of *JGCD* (plu@iastate.edu)
Guest Editors: Moriba Jah (moriba.jah.1@us.af.mil) and Marcus J. Holzinger (holzinger@gatech.edu)

AIAA NEW ENGLAND SECTION STUDENT CHAPTERS GATHER AT MIT

Representatives from every active Student Branch in the New England Section gathered at MIT on 29 September to meet students from other branches and section members. Each branch discussed their interests, accomplishments, and planned activities. The exchange opened up several areas of cooperation and common interest. The 36 attendees were hosted by Ceili Burdhimo from MIT, and presentations were given by Mehmet Akbulut from Boston University; Jamie Davidson and Mike Sola from Daniel Webster College; Ceili Burdhimo, Andrew Buggee, and Greg Allan from Northeastern University; Sarah Buono and Evan Brown from the University of Massachusetts Lowell; Brian Stafford and Kazimir Sheputa from Wentworth Institute of Technology; and Matias Abad from Worcester Polytechnic Institute. In addition, Charles Wilson described Section activities and how students may get involved on the New England Council, Regional Committees, and National Boards. Professor John Blandino discussed the opportunities and requirements for funding of student branch activities by the New England Council.

JOIN THE INSTITUTE'S PUBLIC POLICY ACTIVITIES

AIAA's Public Policy Committee (PPC) recently has undergone a significant reorganization in an effort to become more efficient, more relevant, and better positioned. The new PPC is now composed of six outcome-based working groups, each led by two co-chairs appointed by the Vice President of Public Policy. The working groups (descriptions follow) will focus on Key Issue Development, the Congressional Visits Day Program, Forum Integration, States Advocacy, Engagement Activities, and Honors & Awards. This structure provides every AIAA member with an opportunity to participate in our public policy activities at a variety of levels and as their ability to participate allows. AIAA members interested in serving on one or more of the working groups should contact Steve Sidorek at steves@aiaa.org.

Key Issue Development Working Group

Co-Chairs: Matt Angiulo and Samantha Magill

Each year the PPC establishes public policy key issues (KI) that become the focal points of the Institute's engagement with congressional decision makers, the administration, and state and local officials. Our KIs provide the supporting pillars of the Congressional Visits Day program, drive panel sessions at our annual forums, underpin our state-level advocacy efforts, and form the basis of a number of smaller focused events and activities. In recent years the PPC has created a tighter matrix for KIs and with fewer, concise KIs the Institute can direct clearer asks and actions of lawmakers.

The Key Issue Development Working Group (KIWG), with input from the Technical Activities Committee and AIAA members through key issue development workshops, is responsible for identifying, consolidating, and focusing on the critical political issues that affect the aerospace industry as a whole. The KI themes and relevant issues will be reviewed and determined annually by the PPC and presented to the AIAA Board of Directors each January for approval. The KIWG duties include:

- Reviewing, editing, and updating the KI matrix/summary
- Holding key issue development workshops at annual forums
- Identifying and development of new KIs
- Developing, reviewing, editing, and updating the KI supporting information papers
- Identifying, categorizing, and monitoring "Watch Items"

Congressional Visits Day Program Working Group

Co-Chairs: Tim Dominick and Bob Stuever

Every year at Congressional Visits Day (CVD), AIAA members – engineers, scientists, researchers, students, educators, and technology executives – travel to Washington, DC, to meet with national decision makers to discuss critical industry issues in civil aeronautics, civil astronautics, and defense. Through face-to-face meetings CVD raises awareness of the long-term economic and security value that aerospace brings to the United States. The CVD Program Working Group (CVDWG) plans and conducts the entirety of the CVD experience, which includes training activities for the participants, drafting outreach documents for dissemination to congressional staff, establishing the agenda for the day, and facilitating follow-up activities with congressional offices.

Join the CVDWG and play a big part in the success of the program. Your contribution will be relevant and important, and the experience provides unprecedented professional development opportunities beyond the normal AIAA technical or program committees or section leadership. It is a great chance to network, particularly with AIAA corporate members and the AIAA staff, and to understand and gain a perspective of the inner workings of planning a major event in the congressional environment.

Forum Integration Working Group

Co-Chairs: Sandy Coleman and Justin Kugler

The Forum Integration Working Group (FIWG) is responsible for ensuring that AIAA messages, themes, and key issues relating to public policy are most effectively integrated into the annual forums. Working group members will coordinate with each Forum Organizing Committee to:

- Recommend and recruit relevant plenary speakers
- Invite relevant policy experts & policymakers as forum participants
- Design Forum 360 sessions that incorporate public policy thought leadership
- Highlight ongoing public policy activities outside the forums

The FIWG co-chairs will assign each working group member an appropriate forum to focus on (with one member designated as the active lead for each upcoming event), provide guidance on key issues and other relevant AIAA themes and messages, and report on the activities of the working group to the PPC.

Current and past Forum Organizing Committee members are highly encouraged to join the FIWG to ensure continuity and knowledge sharing from year to year.

States Advocacy Working Group

Co-Chairs: Kim Hicks and Steve Justice

The States Advocacy Working Group (SAWG) is responsible for enhancing and expanding AIAA's public policy activities to the state and local levels. To do so, the SAWG will:

- Engage and educate members of Congress during the congressional recess to enhance national efforts
- Engage and educate local and state decision makers on the important role of the aerospace industry both locally and nationally
- Engage more AIAA members in public policy activities

Specifically, we plan to strengthen local section public policy activities by:

- Identifying a State PP Coordinator for those states with multiple AIAA Sections
- Establishing a "State Delegation Visits Day" as a partner event to the established Congressional Visits Day at local congressional offices during recess times
- Partnering with other aerospace groups to hold State Aerospace Days to connect local AIAA members with their local leaders
- Supporting other section-developed events
- Gathering best practices from the sections and providing "how to" resource materials to help the sections grow local public policy activities
- Providing access to national & state-level aerospace industry data

To accomplish these goals the SAWG needs a dedicated group of volunteers consisting of the Regional Deputy Directors, State Coordinators, and AIAA Section Public Policy Chairs. If you have a passion for public policy and want to educate local leaders on the key role of the aerospace industry in your communities, then the SAWG is for you!

Engagement Activities Working Group

Co-Chairs: Kristen Bloschock and Phil Hattis

The Engagement Activities Working Group (EAWG) will work across multiple mediums and forums to educate AIAA members, the public, elected officials, and other key stakeholders about the breadth of the aerospace profession and what it accomplishes, as well as to focus attention on issues important to sustaining progress and advances in the profession. Among the paths for the EAWG's outreach are:

- Use of online and social media to provide policy alerts, viewpoint exchange, newsletters, and blogs

- Webinars addressing focused topics
- Seminars & roundtables that engage, educate, & solicit viewpoints
- Sessions, forums, and in-person outreach activities at non-AIAA events that enable direct interaction and dialogue with the public and elected officials
- Events that facilitate information and knowledge exchange with government stakeholders, educators, and students

To accomplish these EAWG goals requires the active involvement by AIAA members that seek to be effective outreach leaders. Because successful engagement activities require strategies that vary by target audience, the EAWG needs participation by AIAA members of all ages from across its areas of interest.

Honors & Awards Working Group

Co-Chairs: Dennis Granato and Stephanie Van Y

The Honors & Awards Working Group (HAWG) within the PPC has been established to focus efforts in nominating exceptional candidates for the annual policy and public services related awards, including the Public Service Award, the Durand Lectureship, and the Section Awards. The HAWG is responsible for soliciting nominees from AIAA membership, technical committees, and sections; evaluating those nominees; and making recommendations to the PPC. If you would like to facilitate the honoring of exceptional individuals in our industry we would enjoy having you as part of the team.

AIAA FOUNDATION
Advancing Aerospace

As the year comes to an end, we count our blessings and think about giving back to those organizations that have helped us grow and prosper in our profession.

Please join the AIAA Foundation Board of Trustees and many other AIAA members, who have already donated to the AIAA Foundation. Your support is critical to continuing to enhance and offer the educational programs, conferences, and competitions that underpin our long-standing legacy to attract, educate, and support tomorrow's aerospace leaders so that they can shape the future of aerospace.

The Institute strongly believes in the importance of our educational programs and will match individual and corporate donations up to $1 million dollars (of unrestricted funds). To learn more and to donate, please visit **www.aiaafoundation.org**.

AIAA K–12 STEM ACTIVITIES

Supriya Banerjee and Angela Diggs, AIAA K–12 STEM Section Engagement and Best Practices Committee

The AIAA Foundation recently established the K–12 STEM Committee; the committee has several working groups focused on various aspects of K–12 STEM programming across AIAA. The Section Engagement Working Group's role is to maintain awareness of K–12 STEM activities in the sections and communicate those activities to sections/regions to promote strong K–12 STEM programming across AIAA. Each month we will highlight an outstanding K–12 STEM activity; if your section would like to be featured, please contact us directly.

Tucson Kids Club Builds STEM Connections

Elishka Jepson and Michelle Rouch

Despite the vast research in STEM, little effort is being focused on an artistic angle to approach kids with a vehicle to draw their attention to aviation and aerospace sciences. Children are creative by nature. Children are born scientists and by catching them early, we can focus their energy to harvest their instinctive nature to create.

The AIAA Tucson Section established Kids Club in 2004; since then, the section has built a challenging, yet fun program for 4th–6th graders. Each month during the school year, the Tucson Section partners with local engineers, scientists, and other experts to offer hands-on seminars, covering a variety of STEM plus Art topics, creating STEAM. The Arizona/NASA Space Grant has been a tremendous partner in providing space for the sessions at the University of Arizona, as well as session materials. During the past year, Kids Club has offered sessions including aviation, optics, planetary science, rocketry, and systems engineering. Finding local partners in academia and industry for each event helps keep the activities fresh and interesting to students, and simplifies the execution and planning for the section.

In addition to local STEAM partners participating, Kids Club is a great outlet for showcasing aerospace-related subjects that section members are passionate about. One popular annual event is the Engineering/Art session mimicking a real-life experience in conjunction with a competitive art project to develop, design, and execute a unique rendition of the four forces of flight, and orate their final design in order to win. Tucson Section member Michelle Rouch uses art as tool to simulate a mini-engineering acquisition program. Another session that captivates the student's attention year after year is rocket building. The session leader, Steve Lubliner, is a Tucson engineer who knows how to communicate the complexity of rocketry at a kid's level. There is nothing more exciting than seeing a rocket you created launch high into the air! If the kids can conceive it, they can build it.

AIAA Kids Club gives these kids the tools that they thirst for in learning. The Kids Club concept can be applied to any section. A good starting point would be to build a partnership with local clubs that have similar objectives in creating a strong technical community. By working together, the goal of bringing STEAM to students can be achieved faster than by working alone.

If your local AIAA section is interested in starting a Kids Club, or are looking for STEAM activities to inspire children's interest in aerospace engineering, feel free to contact Elishka Jepson, Region VI STEM K–12 Outreach Deputy Director, at elishka.jepson@raytheon.com.

The 2015 Reuben H. Fleet Scholarship recipients (left to right): Man-Yeung Tsay (University of California, San Diego [UCSD]), Laura Andersen (UCSD), Haley Antoine (Academy of Our Lady of Peace), Bryan Martin (Otay Ranch High School), Brianna MacNider (UCSD), Rachel Rybarczyk (UCSD/San Diego State University [SDSU]), Benjamin Martin (UCSD), Enrico Santarpia (SDSU), Adrienna Yan (UCSD), Sean Davis (SDSU), Alex Fleet (Grandson of Reuben H. Fleet), Deepak Atyam (UCSD) (not pictured).

REUBEN H. FLEET SCHOLARSHIPS AWARDED BY THE SAN DIEGO SECTION

The AIAA San Diego Section awarded the Reuben H. Fleet Scholarships at the AIAA San Diego Honors and Awards Banquet on 5 May 2015. Since 1983, 176 students have received the scholarship, which is made possible by the Reuben H. Fleet Foundation at The San Diego Foundation.

SANDY MAGNUS: EASE TRAVEL RESTRICTIONS FOR GOVERNMENT EMPLOYEES

In early November, *The Washington Post* ran an opinion piece by Sandy Magnus (**https://www.washingtonpost.com/opinions/loosen-the-strings-on-travel/2015/11/01/f6a85464-7ce9-11e5-b575-d8dcfedb4ea1_story.html?postshare=1681446466964997**), which explained how onerous restrictions on federal workers' travel to pertinent meetings have consequently diminished collaboration with their private sector peers. The op-ed included stories from a few AIAA members illustrating the benefits of scientific conferences to their research and the advancement of their careers. It also described the Institute's continued advocacy efforts calling on Congress to ease travel restrictions on federal employees attending science and technology conferences. We encourage all members positively impacted by scholarly conferences to contribute to this effort by visiting **www.aiaa.org/yourstory**.

OBITUARIES

AIAA Fellow Yates Died in August

Ivan Yates died on 2 August 2015. He was 86 years old.

Mr. Yates studied Mechanical Engineering at Liverpool University before joining the English Electric Company as an apprentice. While at English Electric he worked on research on emerging new problems posed by high-speed flutter and vibration during high-speed flight. In 1954, he was placed in charge of all flutter and vibration work, and three years later he was responsible for the aerodynamic work on a project that became the basis for the TSR2 aircraft.

After the TSRS's cancellation, Mr. Yates worked on the development of supersonic fighter aircraft for his company, which had become the British Aircraft Corporation. He lead the development of the Jaguar aircraft and then managed the Tornado program. After being promoted to the board of what was now British Aerospace he continued to promote the development of the next generation of fighter aircraft, including the Typhoon.

Mr. Yates retired from BAe in 1979, and was honored with the CBE in 1982 for his work in the aviation industry. In 1991, he became a visiting professor in the Department of Engineering at the University of Cambridge. Among his other honors, he was awarded with a Gold Medal from the Royal Aeronautical Society, and the 1990 AIAA Wright Brothers Lectureship in Aeronautics. He was also a fellow of the Institute of Mechanical Engineers, Royal Aeronautical Society, and The Royal Academy of Engineering.

AIAA Fellow Taylor Died in October

Richard "Dick" Taylor died on 4 October at age 93. He was best known for his work on extended-range twin-engine operational performance standards (ETOPS).

After receiving a bachelor's degree in mechanical engineering from Purdue University, Mr. Taylor joined Boeing in 1946 after serving in World War II as a U.S. Army artillery spotter pilot. He worked as a flight-test engineer in many positions, among them as test pilot on the B-47 Stratojet and the KB-29 aerial tanker.

Over the years, Mr. Taylor held a number of Boeing management positions, including chief of flight test, director of engineering at the Wichita Division, director of engineering for the 737 and vice president of product development at the Renton Division. He retired from Boeing in 1991.

Beyond his work at Boeing, Taylor served as a director at the Museum of Flight in Seattle and at the Experimental Aircraft Association, and he set nine world speed records in his Piper Aerostar.

Besides being an AIAA Fellow, he was also a fellow of the Society of Experimental Test Pilots. He received the FAA Distinguished Service Award, the 1992 National Aeronautics Association Elder Statesman of Aviation Award, and the 2010 *Aviation Week* Phillip J. Klass Lifetime Achievement

Laureate Award. He also was awarded the 1998 William Littlewood Memorial Lectureship.

Former AIAA President Mueller Died in October

George E. Mueller, who led NASA's human spaceflight efforts through the first moon landing, died on 12 October. He was 97.

Mr. Mueller earned his bachelor of science in electrical engineering from the Missouri School of Mines in 1939 and a masters of science from Purdue University in 1940. After working at Bell Laboratories, Mr. Mueller became a professor of electrical engineering and systems engineering at The Ohio State University (OSU) in 1946, where he established a vacuum tube laboratory and headed up the university's communication engineering group. He also worked on his doctorate in physics, which he obtained in 1951.

In 1953, Mr. Mueller took a sabbatical from OSU to work for the Ramo-Wooldridge Corporation (now part of TRW Corporation), where he was involved with radar designs for the Titan missile. He joined Ramo-Wooldridge full-time in 1957 to direct the firm's Electronic Laboratories, before joining NASA in 1963 to oversee the Apollo project.

During his time on the Apollo project, Mr. Mueller instituted several reforms to NASA's internal structures, establishing the Office of Manned Space Flight (OMSF), and consolidating three of NASA's centers, the Manned Spacecraft Center (now the Johnson Space Center), the Marshall Space Flight Center, and the Kennedy Space Center, under the OMSF – allowing for more streamlined operations that took into account each center's particular competency and strengths. Mueller also employed his "all-up" theory that reduced cost overruns and delays in the project. Instead of certifying each state of the rocket separately this plan involved examing all parts to be checked at one. This theory was greeted with skepticism, but it was later embraced making it the testing standard for the remainder of the program.

In 1965, Mr. Mueller established the Apollo Applications Program to find ways to use Apollo technology and lessons-learned to advance the U.S. space program. This program helped to produce Skylab, America's first space station. Mr. Mueller was also a staunch advocate for a reusable space transportation system, and some experts considered him to be the "father" of the space shuttle program.

Mr. Mueller resigned from NASA in 1969, four months after the first moon landing. He served as General Dynamics senior vice president and as chairman and chief executive officer for System Development Corp. (SDC). His desire to develop a lowe cost method to access space, led him to Kistler Aerospace, a commercial spaceflight company, where he worked from 1995 to 2004.

In addition to his professional positions, Mr. Mueller, an AIAA Honorary Fellow, served as the president of AIAA and the president of the International Academy of Astronautics. His many other honors included the 2011 National Air and Space Museum Trophy, the 2002 National Space Trophy, the 1986 AIAA Elmer Sperry Award, the 1983 AIAA Goddard Astronautics Award, and the 1971 National Medal of Science in Engineering.

AIAA Fellow Robert Farquhar Died in October

Robert W. Farquhar, a retired NASA astrodynamicist, died on 18 October. He was 83 years old.

After serving in the U.S. Army and being deployed to Korea inthe early 1950s, Dr. Farquhar earned a bachelor's degree in aeronautical engineering in 1959 from the University of Illinois, and a master's degree in engineering from the University of California at Los Angeles in 1961. He worked at Lockheed Missiles and Space Company while working on his Ph.D. from Stanford University, which he earned in 1969.

From 1969 to 1990, Dr. Farquhar worked for NASA Goddard Space Flight Center and NASA Headquarters, holding a number of positions that included studies of post-Apollo lunar exploration concepts, the lunar shuttle transportation system, and key management positions for numerous satellite projects.

In 1990, Dr. Farquhar began working for Johns Hopkins University Applied Physics Laboratory (APL). He used his design skills and space mission experience to support APL's role in NASA's Discovery Program. He was the flight director for the Near Earth Asteroid Rendezvous (NEAR) mission to 433 Eros, which became the first spacecraft to observe and land on an asteroid. He also worked on other projects such as the Comet Nuclear Tour, and the MESSENGER mission to Mercury. Dr. Farquhar was the first mission manager for the New Horizons project.

Dr. Farquhar wrote or contributed to many papers and books, including *Analog Studies of the Limit Cycle Fuel Consumption of a Spinning Symmetric Drag Free Satellite* and *Fifty Years on the Space Frontier: Halo Orbits, Comets, Asteroids, and More*. He was honored with the 1981 AIAA Mechanics & Control of Flight Award for unique and sustained contributions to the technology of the control and application of libration-point satellites resulting in the successful flight of the world''s first libration point mission.

Former President of the American Rocket Society Died in October

Frederick C. Durant III, who was president of the American Rocket Society (which merged with the Institute of the Aerospace Sciences to create AIAA) from 1953 to 1954, died on 21 October. He was 98 years old.

Mr. Durant graduated from Lehigh University in 1939. He enlisted in the U.S. Navy as an aviator during World War II, and taught pilots how to land on and takeoff from aircraft carriers. After the war, Mr. Durant joined Bell Aircraft as a test pilot, testing some of the first fighter jets in the U.S. inventory. During the Korean conflict, he returned to military service, serving as a U.S. Navy test pilot.

After returning from the Korean conflict, Mr. Durant became one of the nation's most respected advisors on aerospace technology – working with a number of organizations, including Bell Aircraft Corp., the Everett Research Lab, the Naval Air Rocket Test Station, and the Maynard Ordnance Test Station. In 1953, he served on a panel organized by the CIA for the purposes of investigating if extraterrestrial spacecraft existed, helping to author the committee's report, which found "no evidence that the phenomena indicate a need for the revision of current scientific concepts." Additionally, during the same period Mr. Durant became a staunch advocate for manned spaceflight, penning an article for *Aviation Week* magazine arguing that not only was spaceflight feasible, it was time for the U.S. to invest in a manned spaceflight program. His advocacy attracted the notice of Dr. Wernher von Braun, who recruited Mr. Durant for his Project Orbiter program, with the goal of putting a U.S. civilian satellite into orbit around the Earth. The program led to the creation of the Explorer I satellite, launched in 1958.

The Smithsonian Institution hired Mr. Durant in 1964 to lead its efforts to add an aerospace component to the Institution's museums. Serving as assistant director of astronautics at the National Air And Space Museum until 1981, his efforts ensured that the Smithsonian became the official repository for all of NASA's spacecraft and equipment. The museum opened in 1976.

After retiring from the Smithsonian, Mr. Durant was a consultant and historian with Intelsat. He was president of the International Astronautical Federation from 1953 to 1956 and former governor of the National Space Club in 1961.

CALL FOR NOMINATIONS

Recognize the achievements of your colleagues by nominating them for an award! Nominations are now being accepted for the following awards, and must be received at AIAA Headquarters no later than **1 February**.

Any AIAA member in good standing may serve as a nominator and are urged to read award guidelines to view nominee eligibility, page limits, letters of endorsement, etc. Please note that the nomination form, related materials and the three required AIAA member letters of endorsement must be submitted to AIAA by the nomination deadline. Nominators are reminded that the quality of information is most important.

AIAA members may submit nominations online after logging into www.aiaa.org with their user name and password. You will be guided step-by-step through the nomination entry. If preferred, a nominator may submit a nomination by completing the AIAA nomination form, which can be downloaded from **http://www.aiaa.org/OpenNominations/**.

Awards are presented annually, unless otherwise indicated. However AIAA accepts nomination on a daily basis and applies to the appropriate award year.

Aerospace Power Systems Award is presented for a significant contribution in the broad field of aerospace power systems, specifically as related to the application of engineering sciences and systems engineering to the production, storage, distribution, and processing of aerospace power.

Air Breathing Propulsion Award is presented for meritorious accomplishment in the science of air breathing propulsion, including turbomachinery or any other technical approach dependent on atmospheric air to develop thrust, or other aerodynamic forces for propulsion, or other purposes for aircraft or other vehicles in the atmosphere or on land or sea.

The industry-renowned **Daniel Guggenheim Medal** was established in 1929 for the purpose of honoring persons who make notable achievements in the advancement of aeronautics. AIAA, ASME, SAE, and AHS sponsor the award.

Durand Lectureship for Public Service, named in honor of William F. Durand, recognizes for notable achievements by a scientific or technical leader whose contributions have led directly to the understanding and application of the science and technology of aeronautics and astronautics for the betterment of mankind.

Energy Systems is presented for a significant contribution in the broad field of energy systems, specifically as related to the application of engineering sciences and systems engineering to the production, storage, distribution, and conservation of energy.

George M. Low Space Transportation Award honors the achievements in space transportation by Dr. George M. Low, who played a leading role in planning and executing all of the Apollo missions, and originated the plans for the first manned lunar orbital flight, Apollo 8. (Presented even years)

Haley Space Flight Award is presented for outstanding contributions by an astronaut or flight test personnel to the advancement of the art, science, or technology of astronautics. (Presented even years)

J. Leland Atwood Award recognizes an aerospace engineering educator for outstanding contributions to the profession. AIAA and ASEE sponsor the award. ***Note***: Nominations should be submitted to ASEE (**www.asee.org**) no later than **15 January**.

Missile Systems Award — Technical Award is presented for a significant accomplishment in developing or using technology that is required for missile systems.

Missile Systems Award — Management Award is presented for a significant accomplishment in the management of missile systems programs.

Propellants and Combustion Award is presented for outstanding technical contributions to aeronautical or astronautical combustion engineering.

Space Automation and Robotics Award recognizes leadership and technical contributions by individuals and teams in the field of space automation and robotics. (Presented odd years)

Space Science Award is presented to an individual for demonstrated leadership of innovative scientific investigations associated with space science missions. (Presented even years)

Space Operations and Support Award is presented for outstanding efforts in overcoming space operations problems and assuring success, and recognizes those teams or individuals whose exceptional contributions were critical to an anomaly recovery, crew rescue, or space failure. (Presented odd years)

Space Processing Award is presented for significant contributions in space processing or in furthering the use of microgravity for space processing, (Presented odd years)

Space Systems Award recognizes outstanding achievements in the architecture, analysis, design, and implementation of space systems.

von Braun Award for Excellence in Space Program Management recognizes outstanding contributions in the management of a significant space or space-related program or project.

The **William Littlewood Memorial Lecture**, sponsored by AIAA and SAE, perpetuates the memory of William Littlewood, who was renowned for the many significant contributions he made to the design of operational requirements for civil transport aircraft. Lecture topics focus on a broad phase of civil air transportation considered of current interest and major importance.

Nominations should be submitted by **1 February** to SAE at **http://www.sae.org/news/awards/list/littlewood/**.

Wright Brothers Lectureship in Aeronautics commemorates the first powered flights made by Orville and Wilbur Wright at Kitty Hawk in 1903. The lectureship emphasizes significant advances in aeronautics by recognizing major leaders and contributors. (Presented odd years)

Wyld Propulsion Award recognizes outstanding achievement in the development or application of rocket propulsion systems.

For further information on AIAA's awards program, please contact Carol Stewart, Manager, AIAA Honors and Awards, carols@aiaa.org or 703.264.7538.

To submit articles to the *AIAA Bulletin*, contact your Section, Committee, Honors and Awards, Events, Precollege, or Student staff liaison. They will review and forward the information to the *AIAA Bulletin* Editor. See the AIAA Directory on page **B1** for contact information.

Upcoming AIAA Continuing Education Courses

Courses at AIAA Science and Technology Forum 2016 (AIAA SciTech 2016)
www.aiaa-scitech.org/CoursesWorkshops

2–3 January 2016

2nd AIAA Aeroelastic Prediction Workshop (Organized by the AIAA Structural Dynamics Technical Committee)
How well do modern computational aeroelastic tools predict flutter? How well do they predict unsteady aerodynamic phenomena? How do choices of spatial and temporal parameters and turbulence model affect the solution? How does the presence of separated flow influence the accuracy of the calculations? These are questions being addressed in the 2nd AIAA Aeroelastic Prediction Workshop (AePW-2). AePW-2 will focus on assessing the state of the art of computational methods for predicting unsteady flow fields and aeroelastic response.

The goals of the workshop are to:

- Provide an impartial forum to evaluate the effectiveness of existing computer codes and modeling techniques
- Identify computational and experimental areas needing additional research and development

Systems Requirements Engineering (Instructor: John C. Hsu, Ph.D.,P.E., AIAA Fellow, INCOSE ESEP)
Requirements analysis and specification development are the most important contribution at the onset of a program/project. It will set a corrective direction to guide the program/project preventing redesign and rework later on. This course will help familiarize you with an effective method for defining a set of requirements of a system. The focus is on the initial problem of space definition, defining user needs, concept of operations, systems, segment, subsystem requirements, and architecture. Gain an understanding of the following requirements of engineering activities: elicitation of requirements, system requirements analysis, requirements integration, interface requirements and control, functional analysis and architecture, requirements management, and verification and validation of requirements. Learn about the principles and characteristics of organizing well-written requirements and specifications.

Key Topics
- Requirements elicitation and analysis leading to concept of operations
- Systems requirements analysis and requirements fundamentals
- Requirements integration and management
- Specification development
- Functional analysis and architecture
- Interface requirements and control

Guidance of Unmanned Aerial Vehicles (Instructor: Dr. Rafael Yanushevsky)
This course presents a rigorous guidance theory of unmanned aerial vehicles. It can be considered as the further development and generalization of the missile guidance theory presented in the author's book, *Modern Missile Guidance* (2007). Guidance of the unmanned aerial vehicles (UAVs) differs from missile guidance. Its goal is different. Moreover, since UAVs can perform variety of functions, the goal depends on a concrete area of their application. To address a wide class of guidance problems for UAVs, a more general guidance problem is formulated and a class of guidance laws is developed. In addition, the obstacle avoidance problem for UAVs is discussed and avoidance algorithms are considered.

Key Topics
- Generalized guidance laws for UAVs
- Waypoint guidance problem
- Rendezvous problem
- Conditional rendezvous problem
- Guidance of a swarm of UAVs
- Obstacle avoidance algorithms

3 January 2016

Structural Dynamics of Rocket Engines Tutorial (Instructor: Andy Brown, Ph.D.)
Structural dynamics plays a key role in the design, test, and operation of rocket engines. This talk will discuss some of the types of analyses that are required, such as the Campbell Diagram in turbomachinery, the "side-loads" fluid/structure interaction problem in overexpanded rocket nozzles, and the necessity of a system loads model for the generation of interface design loads. The role of modal and hot-fire test for verification will also be discussed. As structural dynamics is frequently a root cause in failure investigations, we'll be able to see some spectacular video of these failures as well.

AIAA Home Study Courses
https://www.aiaa.org/homestudy

Home study courses let you work at your own pace while still providing interface with the instructor. Students receive instructions for completing the course, along with a course notebook, problem sets, and accompanying texts. Over five months, they follow a proven curriculum of reading and homework assignments, and forward completed homework assignments to the instructor for review and comment via mail, email, or fax. The instructor will also answer questions

by email or phone. The time required varies depending on the course and the student's prior knowledge, but in general, amounts to about 20 hours of work per month. Course completion certificates are awarded upon satisfactory completion of all homework assignments. These are self-paced courses.

1 February–30 June 2016

Introduction to Computational Fluid Dynamics (Instructor: Klaus A. Hoffmann)
This introductory course is the first of the three-part series of courses that will prepare you for a career in the rapidly expanding field of computational fluid dynamics. Completion of these three courses will give you the equivalent of one semester of undergraduate and two semesters of graduate work. The courses are supported extensively with textbooks, computer programs, and user manuals. You can use the computer programs to develop your own code, or you may modify the existing code for assigned applications.

Key Topics
- Classification of partial differential equations (PDEs)
- Finite-difference equations
- Parabolic equations
- Stability analysis
- Elliptic partial differential equations
- Hyperbolic partial differential equations
- Scalar representation of the Navier-Stokes equations
- Incompressible Navier-Stokes equations

Advanced Computational Fluid Dynamics (Instructor: Klaus A. Hoffmann)
This advanced course is the second of the three-part series of courses that will prepare you for a career in the rapidly expanding field of computational fluid dynamics. Completion of these three courses will give you the equivalent of one semester of undergraduate and two semesters of graduate work. The courses are supported extensively with textbooks, computer programs, and user manuals. You can use the computer programs to develop your own code, or you may modify the existing code for assigned applications.

Key Topics
- Grid-generation-structured grids
- Transformation of the equations of fluid motion from physical space to computational space
- Euler equations
- Parabolized Navier-Stokes equations
- Navier-Stokes equations
- Grid-generation-unstructured grids incompressible Navier-Stokes equations
- Finite volume schemes

Computational Fluid Turbulence (Instructor: Klaus A. Hoffmann)
This advanced course is the third of the three-part series of courses that will prepare you for a career in the rapidly expanding field of computational fluid dynamics with emphasis in fluid turbulence. Completion of these three courses will give you the equivalent of one semester of undergraduate and two semesters of graduate work. The courses are supported extensively with textbooks, computer programs, and user manuals. You can use the computer programs to develop your own code, or you may modify the existing code for assigned applications.

Key Topics
- Introduction to turbulence and turbulent flows
- Reynolds averaged Navier-Stokes equations parabolic equations
- Turbulence models
- Compact finite difference formulations
- Boundary conditions
- Large eddy simulation
- Direct numerical simulation

Spacecraft Design and Systems Engineering (Instructor: Don Edberg)
This course presents an overview of factors that affect spacecraft design and operation. It begins with a historical review of unmanned and manned spacecraft, including current designs and future concepts. All the design drivers, including launch and on-orbit environments and their effect on the spacecraft design, are covered. Orbital mechanics is presented in a manner that provides an easy understanding of underlying principles as well as applications, such as maneuvering, transfers, rendezvous, atmospheric entry, and interplanetary transfers.

Key Topics
- History
- Design drivers
- Orbital mechanics and trajectories
- Systems engineering
- Design considerations
- Mass, power, and cost estimation